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COMPARISON OF TEST SITE AND OVERSEAS DEPLOYMENT SITE INTERVISIBILITY CHARACTERISTICS

by

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Comparison of Test Site and Overseas Deployment Site Intervisibility Characteristics

by

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ABSTRACT

Intervisibility characteristics are critical to ground combat forces in shaping results of U.S. Army operational tests. An important question is: "Are the results of a test conducted at a specific test site valid for a different deployment site?" This thesis develops a methodology to help answer this question. It commences by tracing the background studies of intervisibility analysis, and then compares by computer simulation the intervisibility characteristics of several sites, and determines which sites are most nearly alike. Transformation equations are developed to facilitate extrapolation of certain continental United States (CONUS) test results to selected outside continental United States (OCONUS) sites.

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I. INTRODUCTION

Operational testing of new equipment and organizations in the U.S. Army is a major part of the Army acquisition and force development system. The purpose of operational testing is to determine how effective an organization, tactic, or item of equipment is when subjected to realistic operational environments. The Army conducts operational testing at continental United States (CONUS) test sites, but plans to fight its potential adversaries in Western Europe, South Korea, and other outside CONUS (OCONUS) areas of national concern. The dichotomy of testing systems and organizations on designated terrain, while planning wartime utilization on different terrain raises an important question, "Are the results of a test conducted at a specific test site valid for a different deployment site?"

Measures of effectiveness (MOEs) and measures of performance (MOPs) are used to define key decision criteria which help determine an operational test outcome. Operational test managers determine if a given system, piece of equipment, or organization is superior to a competing alternative by adhering to a decision process which is heavily weighted on these criteria. Many MOEs are highly dependent upon the existence of intervisibility or line of sight between specified combatants. A few examples of critical MOEs intimately related to intervisibility conditions are: percentage of friendly and percentage of enemy systems detected; percentage of friendly and percentage of enemy systems engaged; percentage of friendly and percentage of enemy systems hit; loss exchange ratio; and time within field of view.

Ground force intervisibility will be investigated with the following objectives in mind. First, determine which CONUS test sites have intervisibility characteristics most similar to selected potential OCONUS theatres of operation. Second, identify transformation functions capable of transforming the intervisibility characteristics of a given CONUS test site to a selected potential OCONUS theatre of operation. Last, develop a valid methodology to accomplish the above intervisibility comparisons and transformations, and describe possible applications in the U.S. Army test community.

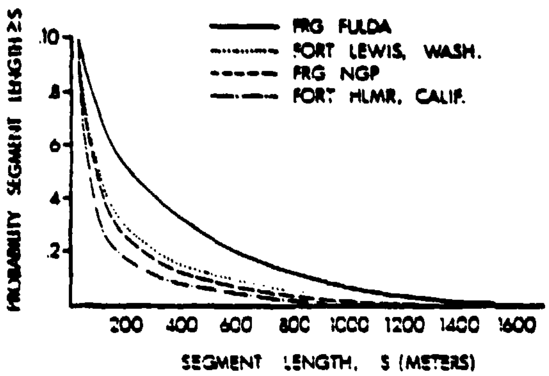
The study will specifically address intervisibility measurements at the overseas deployment sites of Fulda Gap in the Federal Republic of Germany; Cheorwon and Munsan, South Korea; and Qasrod Dasht, Iran. Comparisons and analysis of intervisibility at the above three geographical regions will be made with those test ranges located at Fort Hunter Liggett (FHL), CA, Fort Irwin, CA, Fort Hood, TX, and Yakima Firing Center, WA. Chapter Two explains the evolution of intervisibility analysis from testing on actual terrain to simulation employing digital terrain, and traces the development of intervisibility analysis techniques. Chapter Three describes the conduct of simulations and data analysis used for this thesis, while Chapter Four summarizes the results of these simulations. Finally, Chapter Five provides conclusions and recommendations.

II. DEVELOPMENT OF TEST SITE INTERVISIBILITY MATCHING AND RESULT EXTRAPOLATION

A. HISTORICAL BACKGROUND

Early terrain intervisibility studies conducted by the U.S. Army and its allies were chartered to investigate the effects of terrain on target detections and engagements in combat. [Ref. 1] Studies have been accomplished both manually on the terrain of interest, and by computer simulation utilizing digital terrain maps. Manual tests conducted by the U.S. Army include the Tactical Effectiveness Testing of Antitank Missile Systems (TETAM), conducted in West Germany, Fort Hunter Liggett, CA, and Fort Lewis, WA. Two additional tests of importance include HELAST II, conducted at Fort Knox, KY, and the Swedish S-Tank Agility/Survivability Evaluation (STAGS), accomplished at Fort Knox and Fort Bliss, TX. Chinese Eye was another such test conducted by the United Kingdom (U.K.) in the U.K. zone of West Germany. Review of these studies suggested the TETAM visibility study directed by the U.S. Army Combat Developments Experimentation Command (CDEC) in 1972 is most applicable to this study. TETAM investigated the intervisibility aspects of specific scenarios conducted over varying terrain, specifically the Fulda Gap and North German Plain regions of West Germany, Fort Hunter Liggett, and Fort Lewis. The intervisibility statistics considered in TETAM included probability of line of sight (PLOS), and visible segment lengths. These were gathered by manual observation of a simulated attacking force by a defending force equipped with antitank missiles. Attack routes were designated by the attacking tank commanders, and tank movements were simulated by moving target boards. This aspect of the attack scenario was not considered tactically realistic by subsequent reviews. [Ref. 1] The entire study took well over a year to complete, with the data collection in Germany extending from April through June 1972, and the CONUS sites from September through December 1972. A summary of several intervisibility statistics resulting from the TETAM study is provided in Figure 2.1. Results of the TETAM study are interesting, but applicability to CONUS test site selection is limited due to the small number of sites selected for study, the limited number of intervisibility statistics obtained, and the questionable tactical realism employed.

A second applicable intervisibility study is the Tactical Terrain Intervisibility Classification Study, conducted by the U.S. Army Training and Doctrine Command Analysis Center (TRAC). [Ref. 2] This five year study developed intervisibility information characteristic of military environments, and determined whether a terrain classification system could be developed which could capture these characteristics. [Ref. 2] Twenty-three scenarios were



STATISTICS

TEST SITE OR AREA	NO. INITIATIONS PER ATGM/PATH	P_{LOS}	MEAN SEG LENGTH (m)	S.D. SEG LENGTH	LOSS OF LOS LAND	VEG	CUL
FULDA GAP	2.84	.390	367	358	55%	30%	15%
NORTH GERMAN PLAIN	2.73	.181	183	254	21%	77%	2%
HLMR	6.36	.283	133	207	15%	83%	2%
FORT LEWIS	3.88	.421	190	269	~0%	84%	16%

Figure II-A-1. Summary Statistics of TETAM Visibility Data.

Figure 2.1 Summary Statistics of TETAM Visibility Data simulated in the study, fourteen in West Germany, three in South Korea, four in the Middle East, and two in Australia. Although task organizations were modified to match the terrain involved for some scenarios, the general scheme of maneuver in each scenario was intended to represent a Warsaw Pact (Red) regimental sized force attack on a U.S. (Blue) battalion task force, while employing the appropriate tactics and force dispositions of each. The simulation was run on TRP-GSX, a computer program which was written specifically for the study. TRP-GSX allows the simulated maneuver of selected ground forces over a specific piece of terrain, producing the following intervisibility statistics: probability of line of sight (PLOS), in-view segments lengths, out-of-view segment lengths, first opening range, and expected opening range. Definitions and description of these statistics are provided in Chapter Three.

The Tactical Terrain Intervisibility Classification Study included a development of methodology to estimate intervisibility conditions in a region without resorting to large-scale field tests. This feat was accomplished by development of a predictive model which transformed the inherent Natick Laboratory landform characteristics of specified terrain into the five intervisibility statistics listed above. These models produced predictions that were in error by as much as twenty-five percent. Intervisibility characteristics were found to be highly sensitive to vegetation and urban clutter differences, typically causing much of this error. [Ref. 2]

Apparently no study has been conducted by the U.S. Army to compare intervisibility statistics of CONUS test sites with potential OCONUS deployment sites. This suggests that the results of testing at CONUS test sites have unknown applicability to the OCONUS terrain on which the tested system may be expected to deploy.

B. EXPLANATION OF TRP-GSX

As described previously, the TRP-GSX program was developed by the TRADOC Analysis Center-White Sands Missile Range (TRAC-WSMR). It was used exclusively during the Tactical Terrain Intervisibility Classification Study to determine intervisibility statistics from various simulated battles. TRP-GSX is a highly flexible program, allowing the use of varied digital terrain, and tactical formations which can be realistically modified to match the varied terrain. The output of appropriate intervisibility statistics, coupled with its flexibility, made TRP-GSX the obvious choice for use in this thesis.

The Defense Mapping Agency (DMA) digitized terrain employed in TRP-GSX has elevation and terrain characteristics plotted every 12.5 meters. The established accuracy for DMA digitized terrain is that 90 percent of all well-defined features are accurate to within 25 meters for the horizontal axis, and for the vertical axis, 90 percent of all contour intervals are correct to within one-half contour interval.

TRP-GSX uses a modified DYNTACS line of sight algorithm, which takes an intervisibility polling every second during a prescribed scenario, with one meter range or distance resolution. DYNTACS is a high resolution combat simulation developed by the U.S. Army in the 1960's. The presence or non-presence of intervisibility between attacker and defender are then transformed into the five intervisibility statistics for output. Reasons for loss of intervisibility include terrain blockage, vegetation blockage of more than 100 meters (variable), and blockage due to urban features. Vehicle speeds and heights were set at twenty-five meters per second and two meters respectively for this study. Routes for vehicles are specified prior to the simulation runs, and are designed to simulate the movement of vehicles in realistic tactical formations. Whether or not a particular avenue of approach will support movement of a certain tactical formation is left to the discretion of the simulation planner.

C. INTERVISIBILITY STATISTICS EMPLOYED

This section will provide definitions for the five statistics used in the Tactical Terrain Intervisibility Classification Study as well as in this study, and will offer explanation of their importance.

In-view segment lengths, measured in meters, are defined as the distances travelled along an attack route in which the attacker is visible to a defender. Out-of-view segment lengths are just the opposite, being those distances travelled in line of sight defilade. In-view and out-of-view segment lengths are important intervisibility measures as they provide information about engagement duration at various ranges. This is especially critical for low velocity wire-guided antitank weapons.

First opening range is the distance at which the attacker first becomes visible to the defender. Expected opening range, the mean of all ranges at which a defender gains line of sight with an attacker, is necessarily less than or equal to first opening range; both of which are measured in meters. First opening range and expected opening range give us an indication of where our direct fire weapons should be able to make initial and subsequent engagements of enemy forces. This is an important aspect for all direct fire systems, as maximum ranges and maximum effective ranges may dictate whether a weapon system hits the target. Both also give an indication of standoff range from the target, which can be vitally important to system survivability.

Probability of line of sight (PLOS) is defined as the likelihood intervisibility exists between a defender and attacker. This probability is estimated as a function of range. We would normally expect to find increasing PLOS as the range between attacker and defender decreases. A plot of PLOS versus range does not represent a probability distribution, as "cumulative PLOS" at a given range is meaningless. However, for a given range, the value of PLOS can provide insights into the intervisibility aspects of the terrain being investigated. A PLOS curve provides information about the engagement opportunities available with respect to range. These opportunities are a function of observer height, target height, platform altitude, range, surface clutter, and terrain roughness. [Ref. 2]

D. WHY TEST SITE MATCHING AND RESULT EXTRAPOLATION IS NEEDED

After conducting an operational test of several competing major weapon systems, the decision as to which system is superior must be made. The results of the test depend on the test terrain and environment experienced during the test. It is entirely possible a system which is found superior in a CONUS test may be inferior in a different set of terrain conditions. Due to monetary and political constraints, new systems and organizations are not routinely tested on overseas terrain until late in the acquisition cycle, i.e. full-scale production and fielding. This study will provide a systematic approach designed to quantify how certain CONUS sites and OCONUS deployment sites are similar, then explain how intervisibility statistics can be extrapolated to areas where armed conflict is most likely.

III. CONDUCT OF THE SIMULATION

A. SELECTION OF TEST AREAS AND DEPLOYMENT SITES

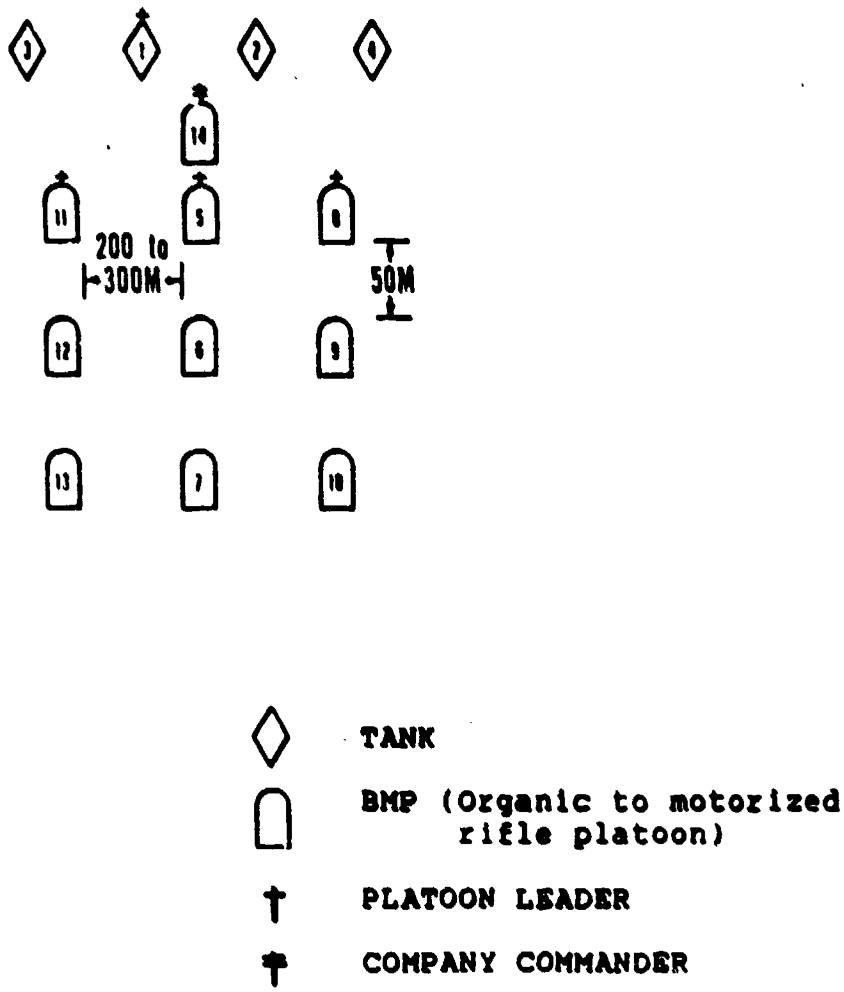
Seven geographical areas were chosen for analysis in this study, three overseas deployment sites and four CONUS test sites. Overseas sites were picked based on their importance to our national interest, and on the availability of digitized terrain. The Fulda Gap area is of vital interest to the U.S. Army, and was selected due to the United States' strong general defense commitments in that area. Cheorwon and Munsan South Korea lie near the demilitarized zone splitting the Korean peninsula, and may experience deployment of units from the Eighth U.S. Army in time of hostilities. One area in Iran, Qasrod Dasht, was selected for study and analysis.

CONUS test site selection was based on historical location of U.S. Army operational testing, and areas currently available for that purpose. Fort Hunter Liggett (FHL) is used heavily for Army operational testing and is the main location used by CDEC. Fort Hood is extensively used for testing by the TRADOC Analysis and Test Activity (TCATA). Yakima Firing Center is utilized for testing by the Army Development and Education Activity (ADEA), and CDEC Board. Fort Irwin currently does not support extensive testing; however, due to the large maneuver area and test support instrumentation already on site, Fort Irwin was analyzed because it is a potential test site.

B. TACTICAL SCENARIO CHOSEN FOR THE SIMULATION

The objective in tactical scenario selection was to select a scenario which could be run realistically at all seven sites being investigated. The tactical force sizes utilized should be supported by the terrain, and the arrays of forces should be doctrinally sound. [Ref. 3,4] To ensure a scenario that was universally valid over all of the sites selected for study, the most restrictive site dictated the force structure simulated for all. Of all sites considered, Fort Hunter Liggett (FHL) was by far the most restrictive, supporting much less than a battalion in the attack and a company in defense. Thus, a Warsaw Pact reinforced motorized rifle company, consisting of ten infantry fighting vehicles (BMP) and four tanks, was chosen as the attacking force. A mechanized infantry platoon equipped with four M2 Bradley fighting vehicles was selected for the defensive force.

The reinforced motorized rifle company was organized to attack in a column of platoons on line with the tank platoon leading in accordance with Soviet doctrine (Figure 3.1). This formation could be doctrinally supported at all of the sites in question, so it was used throughout the study. The U.S. mechanized infantry platoon was positioned facing the motorized rifle company axis of advance, which constituted a



(1) This formation is employed by Warsaw Pact forces 1-3 kilometers from enemy forward line of troops.

(2) The distance between motorized rifle platoons is 200-300 meters.

(3) The distance between BMPs is 50 meters.

(4) The distance between tanks is 100-150 meters.

(5) The BMPs are 100-400 meters behind the tanks.

Figure 3.1 Reinforced Motorized Rifle Company Formation: column of platoons on line, tank platoon leading.

high speed armor avenue of approach. Vehicles organic to the platoon were deployed on line with an interval of 50 to 150 meters between vehicles as dictated by terrain.

C. ALGORITHM USED FOR DEVELOPING SCENARIOS

Once an area of interest was selected for study, e.g. Fulda Gap, the following algorithm was utilized to choose the positions occupied by defensive forces, and attack routes to be followed by the attacking forces. An element of randomness was introduced to help prevent bias in the selection of defensible terrain.

1. Select a random four digit universal transverse mercator (UTM) grid coordinate from the area of interest.

2. Determine if defensible terrain exists in the identified 1000 meter grid square that would accommodate a mechanized infantry platoon battle position. If such terrain exists, proceed to step three; if not, go back to step one.

3. Determine if the chosen platoon battle position can cover a high speed reinforced motorized rifle company avenue of approach with direct fire. If the answer is yes, proceed to step four; if no, return to step one.

4. Position the four mechanized infantry platoon vehicles on line in the designated battle position, allowing 50 to 150 meter intervals between vehicles, depending on the terrain.

5. Position the reinforced motorized rifle company in excess of 4000 meters from the platoon battle position. Thus the attacking force will be located outside of direct fire range of the platoon's organic weapons at the commencement of the simulation. Where the direction of enemy avenues of approach are known, for example Fulda Gap and Korea,

position the reinforced motorized rifle company to approach from that general direction.

6. Using the TRP-GSX program, maneuver the reinforced motorized rifle company along the designated avenue of approach and close with the platoon battle position. The formation employed will be column of platoons on line, tank platoon leading.

7. Replicate this procedure until the desired number of samples are obtained from the simulation.

D. COMPUTER SUPPORT UTILIZED FOR SIMULATION, AND DATA ANALYSIS

The simulation program, TRP-GSX was executed using TRAC-WSMR's Univac 1100/80 computer system, available with Varian interface and Ramtec monitor. Data entry for scenarios was accomplished by key-punching UTM grid coordinates for each vehicle in the platoon battle position, and the center of mass for the lead element of the attacking formation. Turning points on the red axis of advance were designated by grid coordinate to steer the attacking force along its axis of advance. A Programming Language (APL), version 4.0, was used to perform initial data analysis, determining means, standard deviations, and medians. [Ref. 5] Minitab release 5.1 on the IBM 3033 mainframe computer was utilized to determine chi-square statistics through the contingency table method. [Ref. 6] Grafstat Version 1/87, also on the IBM 3033 was used to plot PLOS distributions, quantile-quantile (Q-Q) plots, fitted Q-Q plots, box plots, and frequency histograms. [Ref. 7] The use of Statgraphics version 2.0 facilitated the plotting of additional frequency histograms for non-averaged data. [Ref. 8]

E. SAMPLE SIZES AND DATA OBTAINED

TRP-GSX was programmed to produce statistics by defensive position; thus a read-out of of in-view and out-of-view segment lengths, and first and expected opening range was provided for each platoon battle position. The mean for each of these four statistics was determined, with the two segment length statistics and expected opening range sample sizes ranging from 35 to 320 observations per platoon battle position. First opening range remained constant at 56 observations per platoon battle position, as fourteen targets seen by each of four defending vehicles equals 56. For all the mentioned statistics, one observation is defined as one individual defender gaining or losing line of sight with an individual attacker.

The mean values for in-view and out-of-view segment length, and first and expected opening range were chosen to represent the intervisibility characteristics of each battle position, as data from the TRP-GSX program were historically presented in that form. Twenty platoon battle positions, that is, eighty individual defending vehicles deployed as per the algorithm, were chosen as the sample size for each region investigated. Although a sample size of twenty seems relatively small, each of the twenty means was determined from a much larger sample size as described in the preceding paragraph.

To investigate the validity of employing mean values versus raw observations, histograms were plotted for the Fulda Gap scenario, one using the platoon battle position means (Figure 3.2), and the other with raw observations (Figure 3.3). At issue was the normalizing effects of the central limit theorem. Normalizing effects did not materialize to any great degree, as inspection of these two different frequency histograms reveals. Therefore, the standard output of means for the first four intervisibility statistics was adopted.

The fifth intervisibility statistic, PLOS, was produced by TRP-GSX as a function of 100 meter increments from 0 to 4000 meters in range. Typical sample sizes for the estimation of PLOS at each range were about 200 observations for each platoon battle position. Combining the results of all 20 iterations produced a quite large sample size of over 4000 observations at each site.

F. COMPARISON OF CONUS TEST SITE AND OVERSEAS DEPLOYMENT SITE INTERVISIBILITY

In choosing a location to test a weapon system, the intervisibility characteristics of terrain should play a role in our decision. To determine how two sections of terrain are similar, intervisibility, trafficability, and

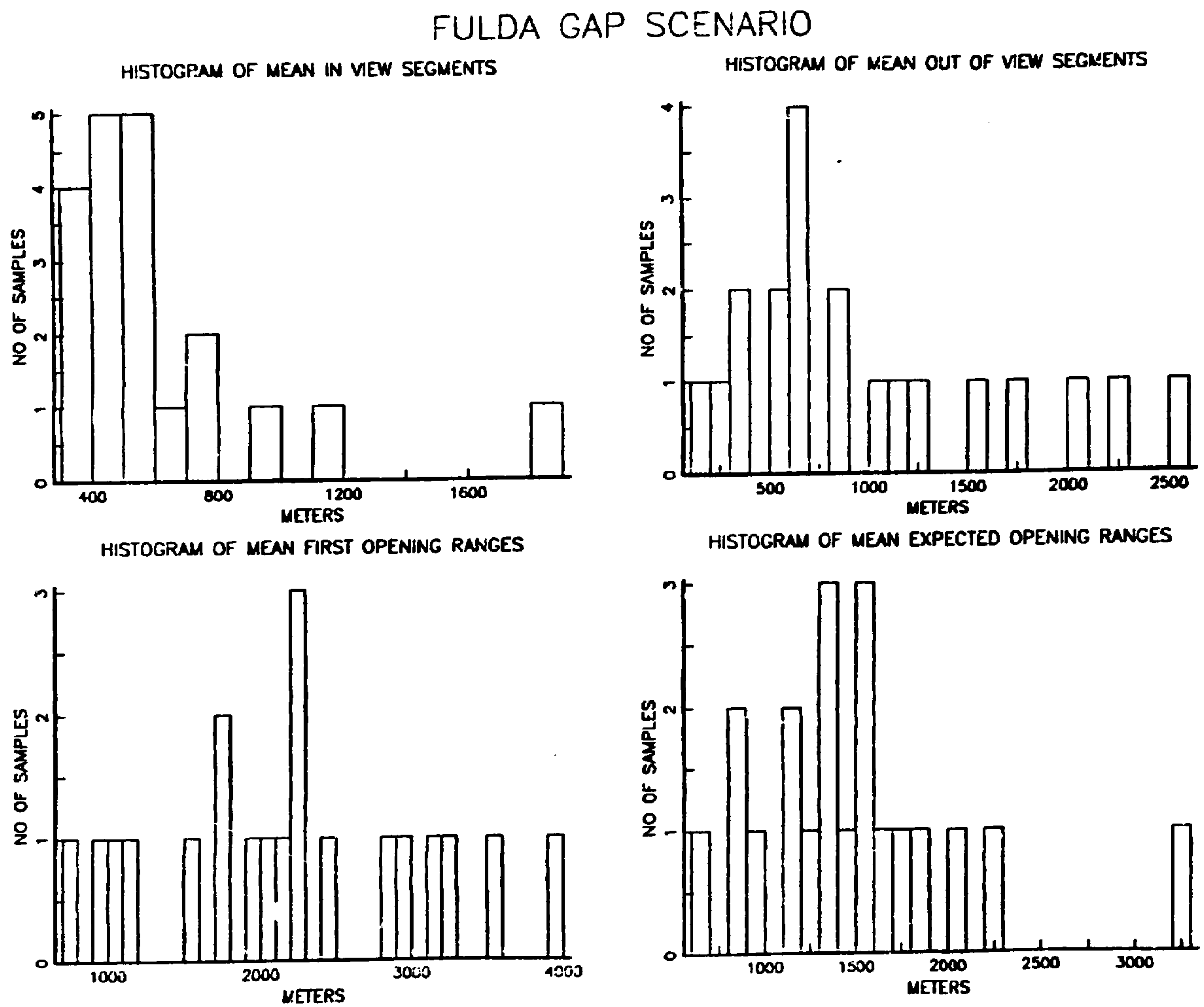


Figure 3.2. Histograms, Fulda Gap Scenario

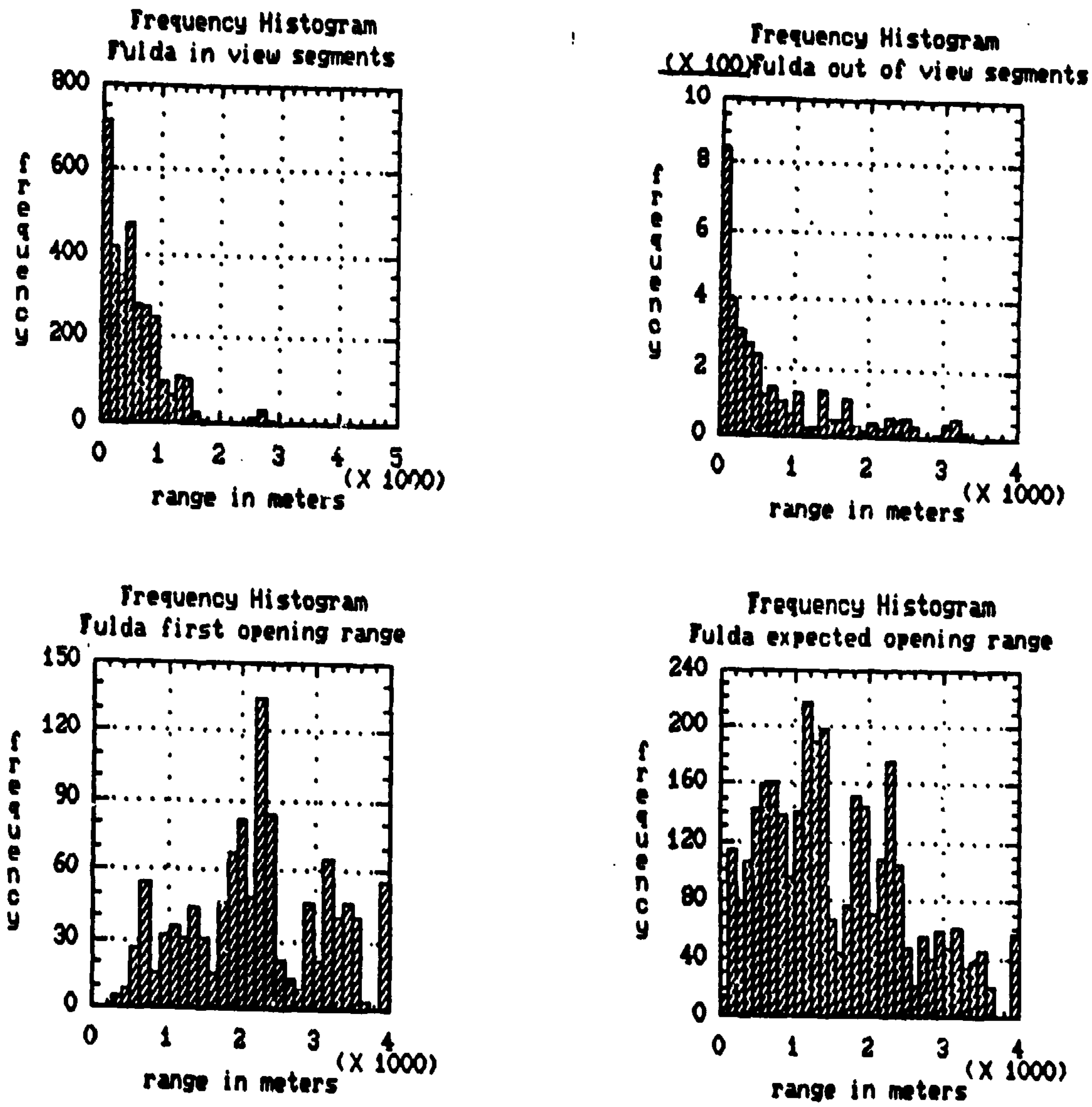


Figure 3.3 Frequency Histograms, Fulda Gap Scenario

meteorological condition comparisons should be made. As this study is limited to investigating intervisibility, this section compares intervisibility characteristics of the seven geographical regions of interest. The format of comparisons will be to first compare Fulda Gap with the four CONUS sites, then likewise sequentially for Qasrod Dasht and South Korea.

For a gross comparison of Fulda Gap with the four CONUS sites, we first explore overall sample mean values (Table 1), overall sample standard deviations (Table 2), and box plots (Figures 3.4, 3.5, 3.6, 3.7) obtained for each region. Table One shows the means for in-view and out-of-view segment lengths, first and expected opening range, and PLOS. Based on the sample of simulation iterations, the Fulda Gap mean in-view segment length appears most like Fort Hunter Liggett (FHL) and Fort Hood. Fulda Gap mean out-of-view segments, mean first opening range, and mean PLOS apparently fail to align closely with any of the CONUS test sites. Mean expected opening range seems closest to that of FHL in this gross comparison. Table 2 exhibits sample standard deviations for all seven scenarios. These statistics give a rough indication of the lateral spread of values for each scenario's intervisibility results. Fulda Gap has similar standard deviations to FHL for all intervisibility statistics except out-of-view segment length. In-view

TABLE 1. SAMPLE MEAN VALUES FOR EXECUTED SCENARIOS
(BASED ON TOTAL DATA)

	IN-VIEW	OUT-OF-VIEW	FIRST OPEN	EXP OPEN	EXP PLOS
FULDA GAP	553	761	2201	1561	.398
QASROD DASHT	878	703	2776	2024	.547
SOUTH KOREA	452	1008	1864	1484	.311
FT HUNTER LIGGETT (FHL)	507	1158	1551	1214	.286
FT IRWIN	741	535	3052	1973	.579
YAKIMA	1238	429	3508	2434	.748
FORT HOOD	611	1554	1332	1093	.279

TABLE 2. SAMPLE STANDARD DEVIATIONS FOR EXECUTED SCENARIOS (BASED ON TOTAL DATA)

	IN-VIEW	OUT-OF-VIEW	FIRST OPEN	EXP OPEN	PLOS
FULDA GAP	511	860	911	929	.255
QASROD DASHT	940	912	1100	1202	.180
SOUTH KOREA	506	1124	1036	978	.261
FT HUNTER LIGGETT (FHL)	597	1222	941	855	.266
FT IRWIN	853	811	1179	1283	.114
YAKIMA	1218	611	675	1329	.097
FORT HOOD	481	1316	457	526	.348

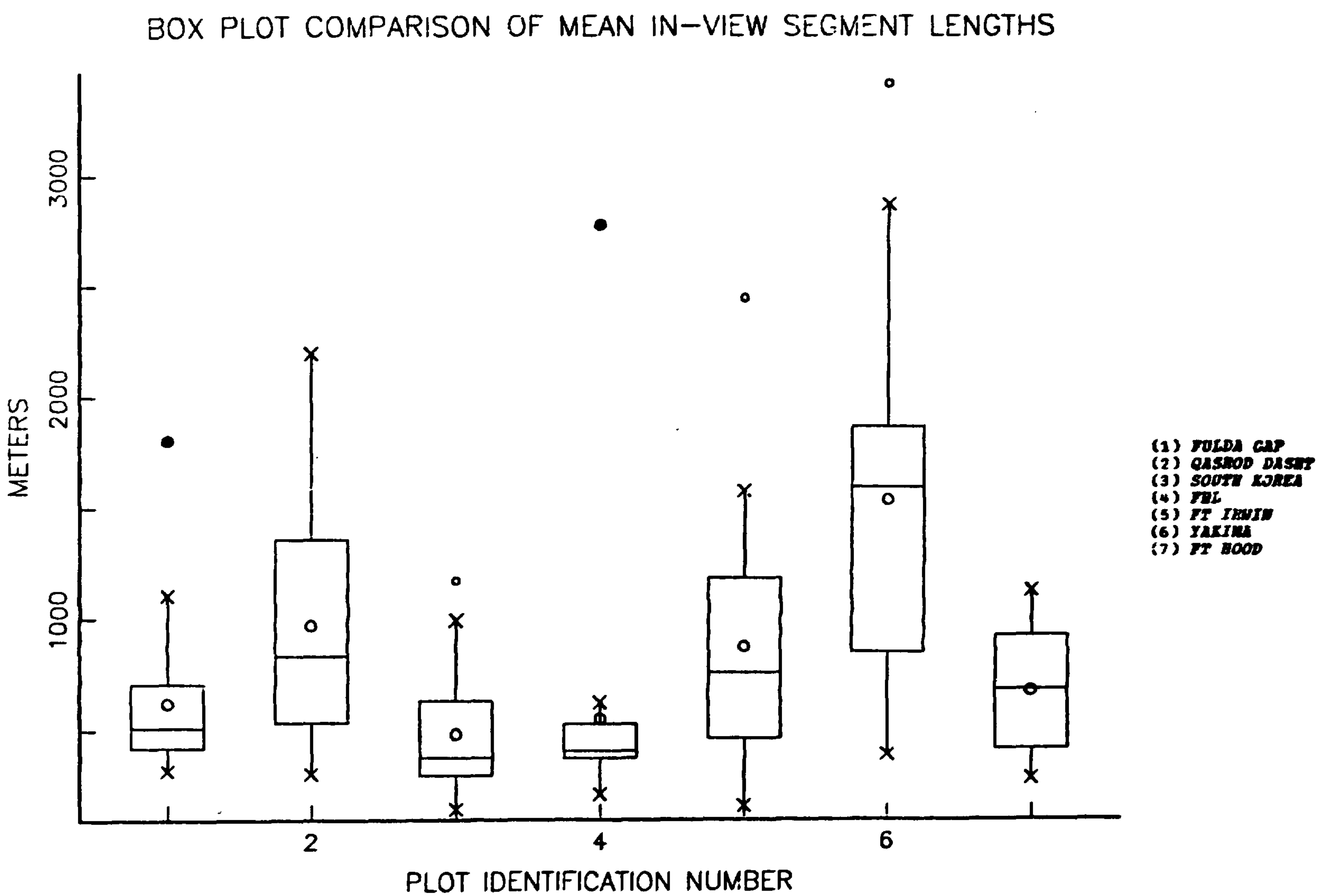


Figure 3.4 Box Plot Comparison of Mean In-View Segment Lengths

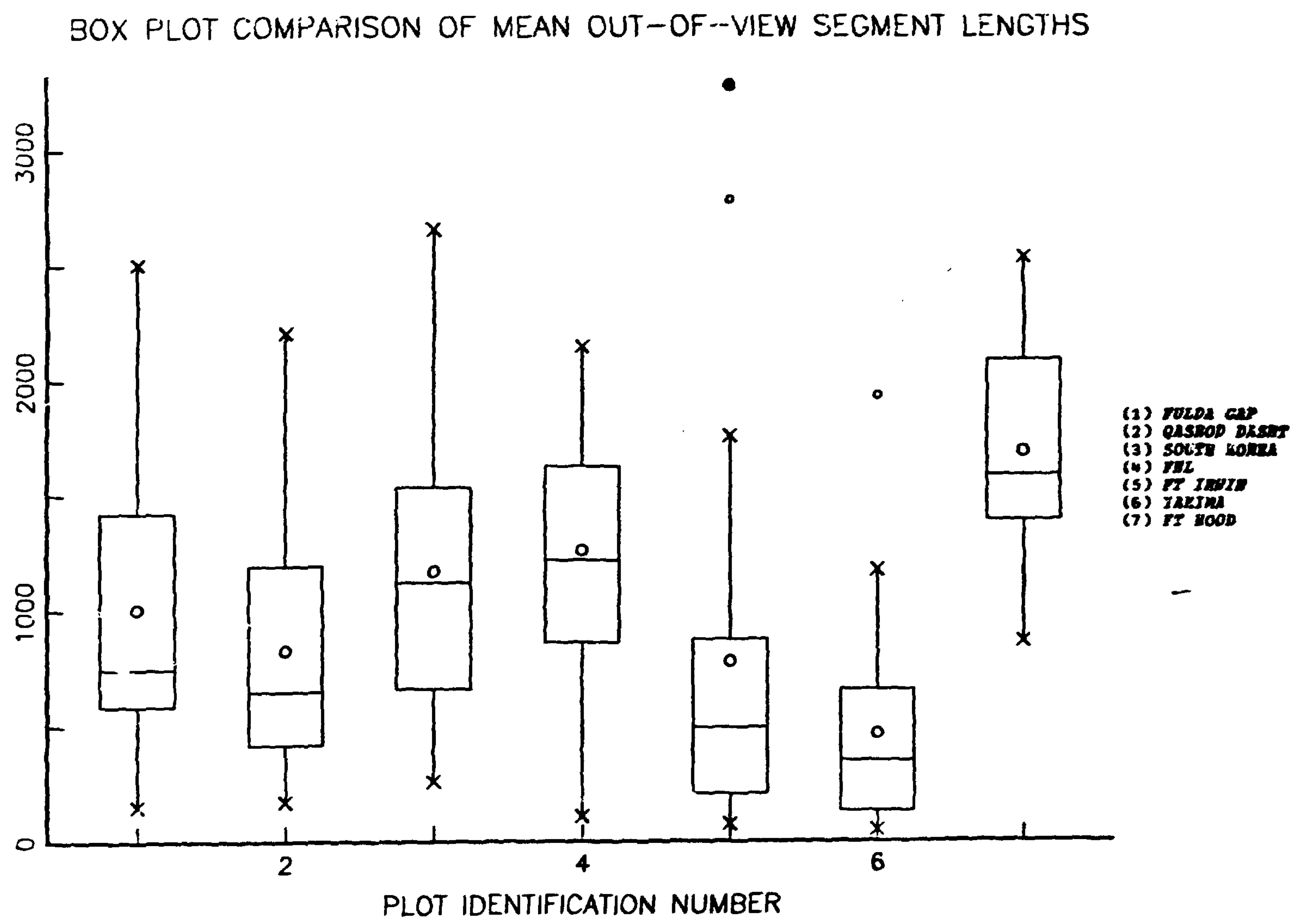


Figure 3.5 Box Plot Comparison of Mean Out-of-View Segment Lengths

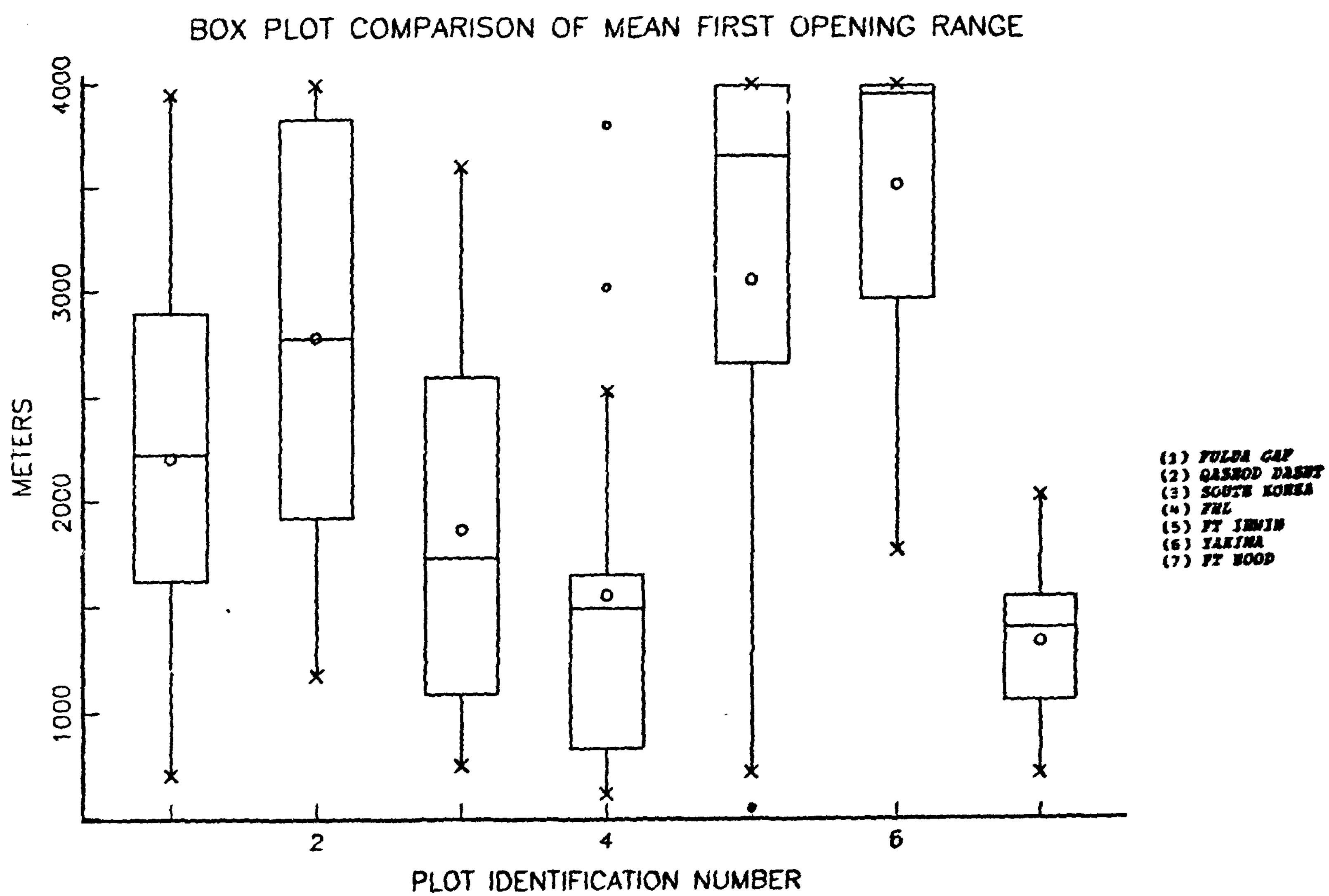


Figure 3.6 Box Plot Comparison of Mean First Opening Range

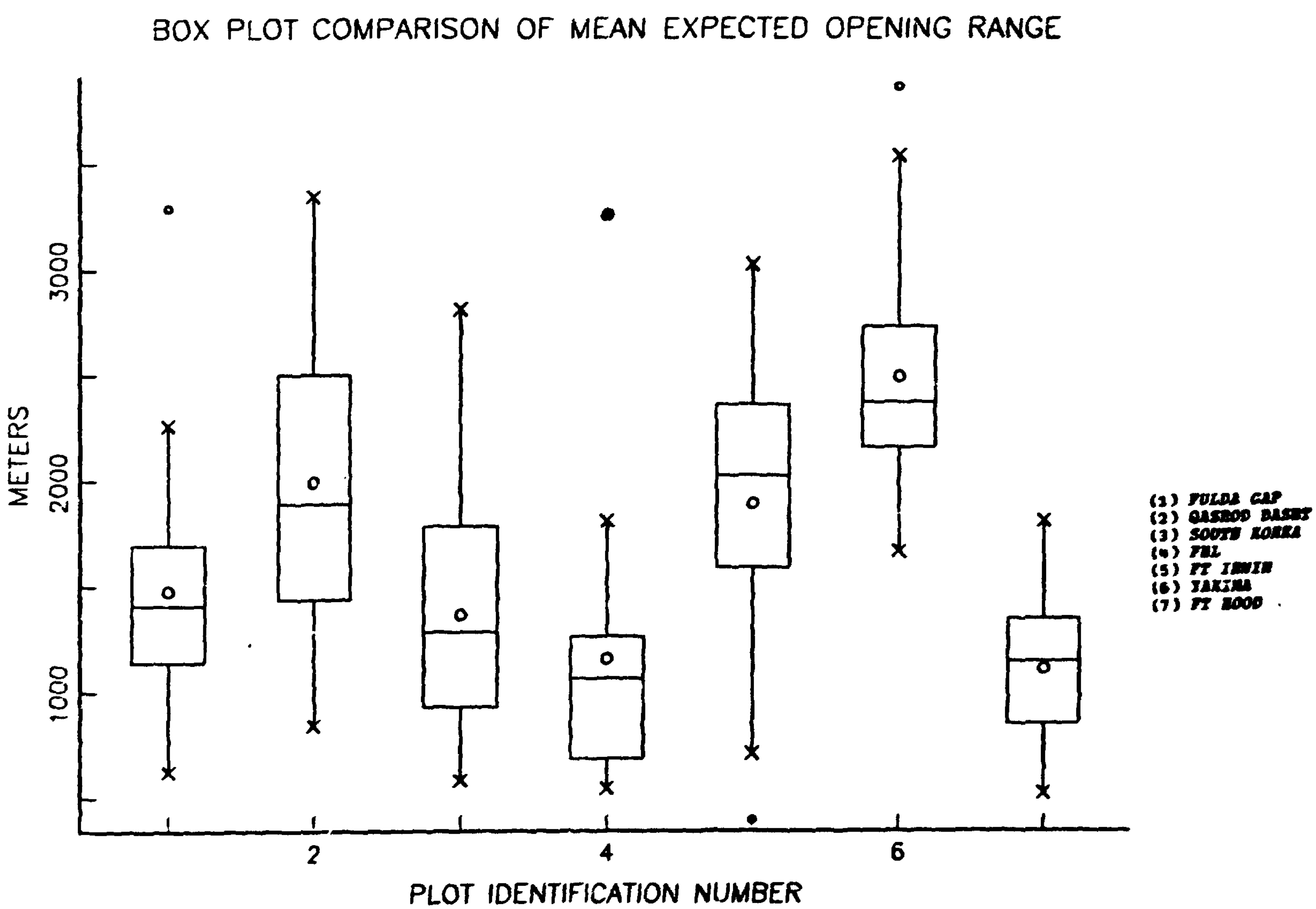


Figure 3.7 Box Plot Comparison of Mean Expected Opening Range

segment length standard deviation compares favorably between Fulda and Fort Hood; however, the other four statistics do not.

Box plots of mean in-view segments for all seven scenarios are included as Figure 3.4, while Figures 3.5, 3.6, and 3.7 display mean out-of-view segments, mean first opening range, and mean expected opening range respectively. The means referred to in Figures 3.4 through 3.7 are those of the platoon battle positions produced by each iteration of the simulation. The box plot symbols are interpreted as follows: the horizontal bar inside a box indicates the location of the median, a circle inside the box is the mean, a box delineates the size of the inter-quartile range (IQR); data shown as an "x" lie within one IQR of the median, those shown as a small circle lie within 1.5 IQR, and solid dark circles lie outside 1.5 IQR of the median. Values of the statistics of interest increase as one reads vertically up the plot.

Based on inspection of Figure 3.4, Fulda Gap in-view segment lengths are aligned most closely with FHL and Fort Hood. Mean out-of-view segment lengths, (Figure 3.5), show Fulda closest to FHL and Fort Irwin. Analyzing Figure 3.6, mean first opening ranges, reveals Fulda Gap dissimilar from any CONUS site. Mean expected opening range shown as

Figure 3.7, presents reasonable similarity between Fulda, FHL, and Fort Hood.

The same gross comparison process was next accomplished for Qasrod Dasht Iran versus the four CONUS scenarios. Based on evaluation of overall sample means and sample standard deviations, Qasrod Dasht seems closely matched with Fort Irwin for all five intervisibility statistics. No other CONUS locations favorably compare with this overseas location. Analysis of Figures 3.4 and 3.5, suggests Qasrod Dasht and Fort Irwin are the most similar of the options. Comparison of Qasrod Dasht and Fort Irwin in Figure 3.6 is less convincing, as first opening range distributions are a poor match. Figure 3.7, mean expected opening range, shows Qasrod Dasht and Fort Irwin are aligned somewhat similarly.

For the final set of gross comparisons, South Korea was considered. Across all five statistics shown in Tables 1 and 2, South Korea compares most closely with FHL, with FHL having higher values in all categories except PLOS. Considering the box plot information, South Korea mean in-view and out-of-view segment plots seem most comparable with FHL, and next closest to Fort Hood. Mean first and expected opening range for South Korea appear similar to both FHL and Fort Hood.

Based on this cursory analysis, the OCONUS-CONUS combinations which merit more detailed inspection are: Fulda Gap-FHL, Fulda Gap-Fort Hood, Qasrod Dasht-Fort Irwin, South Korea-FHL, and South Korea-Fort Hood.

More sophisticated comparison techniques follow for the three overseas deployment sites and four CONUS test sites. First, a chi-square goodness of fit test was accomplished using the contingency table method [Ref.9]. Increments 800 meters wide were formed, so there were five increments covering the 4000 meter range for each geographical region. Each overseas deployment site was evaluated pairwise with each CONUS test site, producing the chi-square statistics shown in Table 3. Here a lower test statistic indicates less difference in the two regions being evaluated; however, the degrees of freedom must be considered when determining the significance of a chi-squared test statistic. Selected critical values from a chi-square table are provided in Table 3 to facilitate interpretation of the statistics' significance. Fulda Gap-FHL, Qasrod Dasht-Fort Irwin, and South Korea-FHL seem to be the pairs most alike across the four statistics of mean in-view and out-of-view segment lengths, and mean first and expected opening range. The Fulda Gap-Fort Hood combination shows promise as a runner-up to Fulda-FHL closeness.

TABLE 3. SUMMARY OF PAIRWISE CHI-SQUARE STATISTICS

TEST STATISTIC(TS) / DEGREES OF FREEDOM(DF)

	IN-VIEW TS/(DF)	OUT-OF-VIEW TS/(DF)	FIRST OPEN TS/(DF)	EXP OPEN TS/(DF)
FULDA-FHL	4.11(3)	5.54(3)	9.33(4)	5.02(3)
FULDA-IRWIN	6.89(3)	5.00(4)	15.84(4)	16.32(4)
FULDA-YAK	15.33(4)	5.81(3)	17.09(4)	23.58(4)
FULDA-HOOD	5.72(1)	14.00(3)	14.22(4)	3.95(2)
QASROD-FHL	15.57(3)	6.75(3)	15.44(4)	14.67(4)
QASROD-IRWIN	3.26(3)	4.62(4)	10.51(4)	7.78(4)
QASROD-YAK	8.06(4)	3.15(2)	8.76(4)	8.56(3)
QASROD-HOOD	.09(1)	17.67(3)	20.52(4)	17.02(4)
KOREA-FHL	3.09(1)	1.71(3)	4.39(4)	4.29(4)
KOREA-IRWIN	4.56(2)	11.11(4)	20.51(4)	10.28(3)
KOREA-YAK	17.05(4)	12.52(3)	21.09(4)	22.75(4)
KOREA-HOOD	4.29(1)	7.98(3)	8.97(4)	4.59(3)

CHI-SQUARE DISTRIBUTION TABLE

	P = .75	P = .90	P = .95
DF = 1	1.323	2.706	3.841
2	2.773	4.605	5.991
3	4.108	6.251	7.815
4	5.385	7.779	9.488

A scheme was developed to combine the chi-square results of the four listed statistics, providing a method to indicate the overall closest overseas/CONUS pair. Equation 3.1 was utilized for this purpose. The use of the chi-square .95 quantile with n-1 degrees of freedom as a normalizing factor, facilitated the combination of chi-square statistics with different degrees of freedom. Results of this ad-hoc procedure can be viewed in Table 4. Total adjusted chi-square test statistics for the combinations of Fulda-FHL, Qasrod Dasht-Fort Irwin, and South Korea-FHL are the lowest in their respective OCONUS-CONUS categories. Thus, these combinations are deemed to be the closest OCONUS-CONUS combinations, in terms of the four intervisibility statistics utilized.

$$X^2_{\mathrm{adj}\ total} = \frac{X^2_{in\ view}(DF)}{X^2_{.95}(DF)} + \frac{X^2_{out\ view}(DF)}{X^2_{.95}(DF)} + \frac{X^2_{first\ open}(DF)}{X^2_{.95}(DF)} + \frac{X^2_{\exp\ open}(DF)}{X^2_{.95}(DF)}$$

EQUATION 3.1

To lend support to the results of the chi-square goodness of fit test, the Smirnov test was employed to test whether or not the distributions for the OCONUS-CONUS pairs being analyzed were identical. [Ref. 9] The null hypothesis, Ho: F(x) = G(x) , for all x, is indeed an unrealistic hypothesis if interpreted literally. This is because we know the OCONUS and CONUS populations do not have identical cumulative distribution functions (CDF'S), F(x)

TABLE 4. DETERMINATION OF CLOSEST SCENARIOS (BASED ON CHI-SQUARE TEST STATISTICS)

	IN-VIEW	OUT-OF-VIEW	FIRST OPEN	EXP OPEN	TOTAL
FULDA-FHL	.53	.71	.98	.64	.86*
FULDA-IRWIN	.88	.53	1.67	1.72	4.80
FULDA-YAK	1.62	.74	1.80	2.48	6.64
FULDA-HOOD	1.49	1.79	1.50	.66	5.54
QASROD-FHL	1.99	1.13	1.63	1.55	6.30
QASROD-IRWIN	.42	.49	1.11	.82	.84*
QASROD-YAK	.85	.53	.92	1.09	3.39
QASROD-HOOD	.023	2.26	2.16	1.79	6.23
KOREA-FHL	.80	.22	.46	.45	.93*
KOREA-IRWIN	.76	1.17	2.16	1.31	5.40
KOREA-YAK	1.80	1.60	2.22	2.40	8.02
KOREA-HOOD	1.12	1.02	.95	.59	3.68

NOTE: THE FIRST FOUR COLUMN ENTRIES ARE THE CHI-SQUARE STATISTICS FOR THE LISTED INTERVISIBILITY CHARACTERISTICS. THE TOTAL COLUMN IS DERIVED VIA EQUATION 3.1.

* DENOTES THE SMALLEST SUM OF CHI-SQUARE STATISTICS IN EACH GROUPING OF THE THREE OVERSEAS AREAS CONSIDERED

and G(x) respectively. However, the Smirnov test statistics provide a second indicator of how close the pairs of distributions are. Smirnov statistics are provided in Table 5. Empirical cumulative distribution plots are provided in Appendix A. The test statistic for each plot, T, is defined as shown in Equation 3.2 for the two-sided test employed. In this equation, $S_1(x)$ and $S_2(x)$ are the empirical distribution functions based on the random samples drawn from the selected OCONUS site and CONUS site respectively.

$$T = \mathrm{SUP}_x[\ S_1(x) - S_2(x)\ ]$$

EQUATION 3.2

The point where T is determined is shown in each plot in Appendix A by the doubled-headed arrows. Lower values of T for a scenario pair indicate less difference in the paired CDF's. Smirnov statistics were recorded for each of the four intervisibility statistics, then summed to obtain an overall closeness indicator shown in the total column of Table 5. CDF's for OCONUS and CONUS sites can be distinguished by noting the listed OCONUS CDF is the same for all four displayed graphs. Results were consistent with the combined chi-square measure, as Fulda-FHL, Qasrod Dasht-Fort Irwin, and South Korea-FHL all had the closest OCONUS-CONUS fits. There were minor inconsistencies in the determination of the third and fourth closest combinations for the Qasrod Dasht region.

TABLE 5. DETERMINATION OF CLOSEST SCENARIOS
(BASED ON SMIRNOV TEST STATISTICS)

	IN-VIEW	OUT-OF-VIEW	FIRST OPEN	EXP OPEN	TOTAL
FULDA-FHL	.30	.35	.55	.40	1.60*
FULDA-IRWIN	.35	.35	.50	.45	1.65
FULDA-YAK	.65	.50	.65	.75	2.55
FULDA-HOOD	.25	.55	.65	.35	1.80
QASROD-FHL	.55	.45	.65	.65	2.30
QASROD-IRWIN	.15	.25	.25	.10	.75*
QASROD-YAK	.40	.35	.45	.35	1.55
QASROD-HOOD	.40	.65	.75	.60	2.40
KOREA-FHL	.30	.15	.30	.25	1.00*
KOREA-IRWIN	.35	.45	.60	.45	1.85
KOREA-YAK	.65	.55	.75	.75	2.70
KOREA-HOOD	.30	.45	.45	.30	1.50

NOTE: THE FIRST FOUR COLUMN ENTRIES ARE THE SMIRNOV STATISTICS FOR THE LISTED INTERVISIBILITY CHARACTERISTICS. THE TOTAL COLUMN IS THE SUM OF COLUMNS ONE THROUGH FOUR.

* DENOTES THE SMALLEST SUM OF SMIRNOV STATISTICS IN EACH GROUPING OF THE THREE OVERSEAS AREAS CONSIDERED

An attempt to formally test for equality of PLOS profiles did not reveal interesting results. The equality of OCONUS-CONUS PLOS was tested at selected ranges, which were designated "PHAT" values. These were chosen at 800 meter intervals, in an attempt to reduce inherent PLOS dependency within small range increments. The normal approximation to the binomial distribution was utilized due to the large sample size of 4000 or more observations for each PHAT. Calculated standard normal Z statistics were extremely large for almost all OCONUS-CONUS combinations, due to the large sample sizes and corresponding small variances. Thus, using Fisher's method to combine probability values was not productive, as the vast majority had values of essentially zero.

Further comparisons of the Fulda Gap scenario with CONUS test sites can be viewed in Appendix B. PLOS comparisons are exhibited as Figure B.1 and Figure B.2. Similarities of Fulda Gap, FHL, and Fort Hood are readily apparent. Empirical quantile-quantile (Q-Q) plots of mean in-view and out-of-view segment lengths, and mean first and expected opening range are included for all combinations of sites. Each Q-Q plot is followed by a frequency histogram for the corresponding intervisibility statistic. Histograms were limited to the top three CONUS comparison contenders, as determined from the chi-square test statistics shown in Table 3.

The Q-Q plots are designed to show differences and similarities in two paired distributions. Q-Q plots having data points lying linearly along the solid center line indicate the two distributions are nearly equal. Other linear relationships deviating from the center line indicate the distributions have the same general shape. [Ref.10] Differing distribution shapes can be recognized by non-linear relationships, erratic crossings of the center line, and numerous "outlying" data pairs.

The possibility exists that Q-Q plots of means might indicate linear relationships, although the underlying individual statistics may have different distributions. The central limit effect may be responsible for causing some linear Q-Q plots.

There is a correspondence between the information provided on Q-Q plots and the corresponding frequency histograms. For example, mean in-view segment lengths for Fulda Gap-FHL (Figure B.3), show Fulda as having segment lengths greater than those for FHL in all but one data pair. We then expect the histograms for mean in-view segment length to show FHL more skewed towards short segment lengths than Fulda. This expectation can be verified by examining Figure B.4. Similar analysis and conclusions may be deduced for mean out-of-view segment lengths, and mean first and expected opening range.

Analysis of results summarized in Appendix B reveals the following conclusions about comparisons for the Fulda Gap scenario:

1. the PLOS curve for Fulda Gap seems most similar to those of FHL and Fort Hood,

2. mean in-view segments for Fulda are closest to FHL,

3. mean out-of-view segments are most similar to FHL and Fort Irwin, and

4. mean first and expected opening range similarities exist between Fulda Gap, FHL, and Fort Hood.

Graphical comparisons for Qasrod Dasht and South Korea may be viewed in Appendix C and D respectively. Conclusions concerning results shown in Appendix C are summarized below.

1. The Qasrod Dasht PLOS curve is most similar to that of Fort Irwin; however, Fort Irwin has large gaps of low PLOS near the 1400 and 2700 meter range marks, whereas Qasrod Dasht is smoother.

2. Mean in-view and out-of-view segment distributions, and mean first and expected opening ranges are closest between Qasrod Dasht and Fort Irwin.

3. Somewhat linear relationships are apparent in many of the provided Q-Q plots, suggesting similarly shaped distributions varying in location and scale factors.

Analysis of results in Appendix D, the South Korea comparisons, suggest the following.

1. South Korea and FHL PLOS curves are very closely distributed, with similar shape and magnitude of PLOS across their range. The Fort Hood PLOS curve shows similarities over the same range, but has higher PLOS than South Korea at shorter ranges.

2. For the four remaining intervisibility statistics, FHL compares most favorably with South Korea. Linear relationships between FHL and South Korea exist for each statistic, with mean out-of-view segments and mean expected opening range distributed close to the center line. Fort Hood distributions are second closest to South Korea in all four statistical categories.

3. As in the Fulda Gap and Qasrod Dasht comparisons, linear relationships on completed Q-Q plots are suggested in several cases.

G. EXTRAPOLATION OF EXPERIMENTAL RESULTS

Given a specified operational test mission, the prudent test manager might consider conducting the test on the closest matching available terrain on which the tested system is expected to be employed. Two problems arise. First is the obvious problem of test site availability . If after considering terrain alikeness, the best test site terrain is unavailable, then extrapolation of experimental results should be utilized. Second, it is unlikely one test site can suffice properly for all inferences, thus further showing the need for result extrapolation for overseas areas of interest. This section will describe methods for extrapolating intervisibility results.

Two methods were employed to obtain linear transformation equations for each possible overseas/CONUS combination. The first method concerned transformation equations for PLOS. Values of PLOS for each overseas/CONUS combination were recorded and plotted against each other, producing a data point every 100 meters along the 4000 meter range. A least square line [Ref. 10] was fit to the data. The second method for the other four statistics, mean in-view and out-of-view segments, and mean first and expected opening range, utilized standard Q-Q plots, followed by the same least square line fit procedure. The last four statistics had 19 data points plotted versus 20 as the 20th point was removed as an outlier. The least square line fitting procedure provides a linear approximation for the conversion of CONUS intervisibility statistics to OCONUS. Resulting equations from the procedure are provided in Table 6. Appendix E contains plots in the same customary order as used in Appendices B, C, and D. As should be expected, the best line fits resulted from those scenarios with the closest overall comparisons. Equations from scenarios with poor fits should not be discarded, but the validity of transformations conducted with such equations is probably less than those with good fits. The reader is invited to base transformation validity decisions on the least square line fits exhibited in Appendix E, and by the provided RSQUARED values.

TABLE 6. SUMMARY OF TRANSFORMATION EQUATIONS FOR IN-VIEW AND OUT-OF-VIEW SEGMENT LENGTHS (RSQUARED VALUES SHOWN IN PARENTHESES)

	IN-VIEW	OUT-OF-VIEW
FULDA-FHL	Y = -259.51 + 1.89X (.872)	Y = -329.34 + 1.04X (.916)
FULDA-IRWIN	Y = 202.17 + 0.45X (.846)	Y = 397.03 + .82X (.869)
FULDA-YAK	Y = 185.31 + 0.26X (.875)	Y = 249.16 + 1.76X (.969)
FULDA-HOOD	Y = 117.67 + 0.68X (.730)	Y = -1192.20 + 1.29X (.915)
QASROD-FHL	Y = -1162.70 + 4.79X (.885)	Y = -282.91 + .86X (.905)
QASROD-IRWIN	Y = -37.54 + 1.20X (.946)	Y = 321.64 + .67X (.845)
QASROD-YAK	Y = 36.70 + .66X (.890)	Y = 192.21 + .47X (.969)
QASROD-HOOD	Y = -296.62 + 1.85X (.865)	Y = -1001.40 + 1.07X (.909)
KOREA-FHL	Y = -510.08 + 2.22X (.924)	Y = 40.03 + .87X (.978)
KOREA-IRWIN	Y = 29.01 + .53X (.905)	Y = 703.24 + .60X (.706)
KOREA-YAK	Y = 15.95 + .30X (.907)	Y = 565.48 + 1.36X (.886)
KOREA-HOOD	Y = -82.62 + .82X (.818)	Y = -676.79 + 1.07X (.974)

TABLE 6. SUMMARY OF TRANSFORMATION EQUATIONS FOR FIRST OPENING AND EXPECTED OPENING RANGE (RSQUARED VALUES SHOWN IN PARENTHESES) (Continued)

	FIRST OPENING RG	EXPECTED OPENING RG
FULDA-FHL	Y = 465.15 + 1.15X (.893)	Y = 216.83 + 1.11X (.957)
FULDA-IRWIN	Y = 283.07 + .51X (.818)	Y = 245.34 + .62X (.888)
FULDA-YAK	Y = -1657.10 + 1.08X (.756)	Y = -715.19 + .87X (.978)
FULDA-HOOD	Y = -962.49 + 2.37X (.963)	Y = -85.62 + 1.37X (.940)
QASROD-FHL	Y = 833.67 + 1.31X (.796)	Y = 307.87 + 1.54X (.938)
QASROD-IRWIN	Y = 510.04 + .73X (.812)	Y = 340.73 + .86X (.878)
QASROD-YAK	Y = -1895.30 + 1.32X (.772)	Y = -949.73 + 1.19X (.938)
QASROD-HOOD	Y = -914.50 + 2.80X (.917)	Y = -159.16 + 1.93X (.966)
KOREA-FHL	Y = 297.30 + 1.03X (.853)	Y = 71.46 + 1.17X (.927)
KOREA-IRWIN	Y = 160.98 + .54X (.757)	Y = 88.12 + .66X (.879)
KOREA-YAK	Y = -1560.00 + .96X (.703)	Y = -872.97 + .89X (.921)
KOREA-HOOD	Y = -961.08 + 2.11X (.906)	Y = -292.12 + 1.47X (.967)

TABLE 6. SUMMARY OF TRANSFORMATION EQUATIONS FOR PLOS (RSQUARED VALUES SHOWN IN PARENTHESES) (Continued)

	PLOS
FULDA-FHL	Y = .149 + .868X (.821)
FULDA-IRWIN	Y = -.707 + 1.907X (.728)
FULDA-YAK	Y = -.977 + 1.838X (.491)
FULDA-HOOD	Y = .219 + .643X (.770)
QASROD-FHL	Y = .380 + .584X (.745)
QASROD-IRWIN	Y = -.227 + 1.337X (.718)
QASROD-YAK	Y = -.470 + 1.360X (.540)
QASROD-HOOD	Y = .420 + .458X (.784)
KOREA-FHL	Y = .037 + .957X (.956)
KOREA-IRWIN	Y = -.872 + 2.042X (.800)
KOREA-YAK	Y = -.828 + 1.523X (.323)
KOREA-HOOD	Y = .108 + .729X (.948)

As previously discussed, since many critical measures of effectiveness and performance (MOEs/MOPs) are dependent on intervisibility characteristics, there exist relationships between intervisibility conditions and corresponding measured performance. Determining these relationships for particular MOEs/MOPs in a chosen scenario is not the purpose or in the scope of this paper; however, two hypothetical examples are provided in an attempt to motivate the intervisibility transformation concept.

The first example concerns a test of two competing anti-tank (AT) missile systems being tested at FHL. Suppose the MOE being analyzed is maximum standoff engagement range. System A has an advertised maximum effective range of 2000 meters, while a heavier and more costly system B has a purported value of 2500 meters. Standoff range is important to the survivability of an AT system, but increased range capability is expensive in terms of system weight and acquisition cost.

After conducting the test of the two systems, the mean first opening range of engagements at FHL was found to be 1600 meters. At this point, one might conclude the increased range capability of system B is not worth the additional funds required to procure the heavier system, as engagements over 2000 meters seem to be rare. However, consider how the two systems fare when compared at Fulda Gap instead of FHL.

Utilizing the transformation equation in Figure E.3, a mean first opening range of 1600 meters at FHL is mapped to approximately 2300 meters at Fulda Gap. Thus system A may fall short of providing maximum standoff engagements at the OCONUS site. This CONUS-OCONUS disparity becomes even more pronounced when considering the two systems deployed in Iran. Employing the transformation equation in Figure E.8, 1600 meters at FHL is mapped to approximately 2900 meters at Qasrod Dasht. This result further reinforces the need for system B, which can engage targets at a greater standoff range than system A.

A second hypothetical example includes testing of the same two AT systems, but the MOE being considered is the number of successful target engagements, given that the target is in range of the AT system. System A requires a 25 second firing window of uninterrupted visibility between the AT system and the target for a successful target engagement, while system B requires only 15 seconds. Assuming target speeds of 15 meters per second, system A must have in-view segments of 375 meters to make a successful engagement. System B needs only 225 meters. During the test at Yakima Firing Center, the mean in-view segment length is found to be 600 meters. Both systems can easily make successful engagements with the large segment lengths available. However, transforming the results to Fulda Gap, the mean in-view segment length is approximately 340 meters. (Figure E.1) System B can still accomplish successful engagements at that short of a segment length, but system A often cannot.

In both of the above hypothetical examples, the importance of transforming results to OCONUS sites is demonstrated. Actual operational tests provide similar though perhaps more complicated comparison opportunities for many MOEs/MOPs.

H. CONSISTENCY WITH PREVIOUS STUDIES

Since this study was conducted over some of the same general geographical areas as previous studies, a comparison of results was conducted. The studies selected for comparison to this study include the TETAM study and the Tactical Terrain Intervisibility Classification Study. Since the three studies do not completely overlap in the analysis of the same terrain, there are several gaps in the comparison.

Table 7 provides comparisons for the Fulda Gap area, while Tables 8, 9, and 10 provide similar statistics for Fort Hunter Liggett (FHL), Cheorwon and Munsan South Korea, and Qasrod Dasht Iran. Highlights of the comparisons follow.

Comparisons of means between this study and the Tactical Terrain study are favorable for in-view segments and average PLOS, but not foı ıe other three statistics. This is due to

TABLE 7. COMPARISON OF MEANS AND STANDARD DEVIATIONS BETWEEN SCENARIOS
FULDA GAP

SCENARIO	IN-VIEW SEGMENTS	OUT-OF-VIEW SEGMENTS	FIRST OPENING RANGE	EXPECTED OPENING RANGE	AVG PLOS
FULDA GAP					
CURRENT THESIS	$\bar{X}=553$ $S=511$	$\bar{X}=761$	$\bar{X}=2201$	$\bar{X}=1561$	.375
TETAM	$\bar{X}=367$	n/a	n/a	n/a	.390
TACTICAL TERRAIN	$449\leq\bar{X}\leq679$	$1177\leq\bar{X}\leq1245$	$2655\leq\bar{X}\leq2950$	$2287\leq\bar{X}\leq2525$	$.24\leq\bar{p}\leq.32$

TABLE 8. COMPARISON OF MEANS AND STANDARD DEVIATIONS BETWEEN SCENARIOS FORT HUNTER LIGGETT (FHL)

SCENARIO	IN-VIEW SEGMENTS	OUT-OF-VIEW SEGMENTS	FIRST OPENING RANGE	EXPECTED OPENING RANGE	AVG PLOS
FHL					
CURRENT THESIS	$\bar{X}=507$ $S=507$	$\bar{X}=1158$	$\bar{X}=1551$	$\bar{X}=1214$	.285
TETAM	$\bar{X}=133$ $S=207$	n/a	n/a	n/a	.283
TACTICAL TERRAIN	n/a	n/a	n/a	n/a	n/a

TABLE 9. COMPARISON OF MEANS AND STANDARD DEVIATIONS BETWEEN SCENARIOS SOUTH KOREA

SCENARIO	IN-VIEW SEGMENTS	OUT-OF-VIEW SEGMENTS	FIRST OPENING RANGE	EXPECTED OPENING RANGE	AVG PLOS
SOUTH KOREA					
CURRENT THESIS	$\bar{X}=452$	$\bar{X}=1008$	$\bar{X}=1864$	$\bar{X}=1484$	.311
TETAM	n/a	n/a	n/a	n/a	n/a
TACTICAL TERRAIN	$557\leq\bar{X}\leq933$	$793\leq\bar{X}\leq1114$	$2551\leq\bar{X}\leq3050$	$2276\leq\bar{X}\leq2636$	$.37\leq\bar{p}\leq.38$

TABLE 10. COMPARISON OF MEANS AND STANDARD DEVIATIONS BETWEEN SCENARIOS QASROD DASHT

SCENARIO	IN-VIEW SEGMENTS	OUT-OF-VIEW SEGMENTS	FIRST OPENING RANGE	EXPECTED OPENING RANGE	AVG PLOS
QASROD DASHT					
CURRENT THESIS	$\bar{X}=878$	$\bar{X}=703$	$\bar{X}=2776$	$\bar{X}=2024$	.547
TETAM	n/a	n/a	n/a	n/a	n/a
TACTICAL TERRAIN	$\bar{X}=779$	$\bar{X}=865$	$\bar{X}=3822$	$\bar{X}=3085$	.44

the restriction of maximum force separation of 4000 meters in this study, causing mean out-of-view segments, and first and expected opening range means to be smaller. The Tactical Terrain study had no such restriction imposed, opening the possibility for long range observations. Means for the Tactical Terrain Study are provided in intervals, as these statistics were recorded separately in that study for the Hunfeld and Fulda regions. The TETAM study in-view segments show a smaller mean and standard deviation than does this study, possibly due to the foliage and meteorological conditions experienced in the spring and early summer when the TETAM test was conducted. The current study and the Tactical Terrain study utilized a 100 meter visibility distance through vegetation, which could account for some of the difference.

Statistics in Table 8, the comparison for Fort Hunter Liggett (FHL), show surprisingly close values for average PLOS between this study and TETAM. In-view segments for the TETAM study show a significantly smaller mean and standard deviation, again probably attributable to the reasons cited above.

Since the TETAM study did not include South Korea, Table 9 only provides comparison of the current study and the Tactical Terrain study. Bounded intervals are employed for the Tactical Terrain study means as the values for Cheorwon and Munsan were computed separately. Mean in-view and out-of-view segments, and mean PLOS are reasonably close between the two studies. First opening range and expected opening range are dissimilar, again due to the same 4000 meter restriction. Comments for Table 10, the Qasrod Dasht Iran scenario are identical to the above comments for South Korea.

Although results from the three studies discussed were not found to be identical, the closeness of in-view and out-of-view segment lengths and PLOS between studies is encouraging.

IV. EXPERIMENTAL RESULTS SUMMARY

In this study, comparisons of intervisibility statistics were performed between all possible combinations of CONUS test sites and selected overseas deployment sites. CONUS test sites included Fort Hunter Liggett (FHL), Fort Irwin, Fort Hood, and Yakima Firing Center; while the Fulda Gap area of West Germany, Qasrod Dasht, Iran, and the demilitarized zone of South Korea made up the overseas set. The intervisibility statistics, mean in-view and out-of-view segment length, mean first and expected opening range, and probability of line of sight (PLOS), were generated by a computer-simulated attack of a Warsaw Pact reinforced motorized rifle company against a U.S. mechanized infantry platoon defense.

Gross comparisons of the scenario sample means and standard deviations, Tables 1 and 2, and box plots of the distributions, Figures 3.4 to 3.7, revealed significant correlation between Fulda Gap, FHL, and Fort Hood. Results of chi-square goodness of fit statistics and Smirnov statistics (Tables 3,4), suggest greatest similarity between Fulda Gap and FHL. Graphical plots in Appendix B also support this finding.

The Qasrod Dasht intervisibility characteristics were found to be quite close to those of Fort Irwin, both in gross comparisons and statistical measures. Graphs displayed in Appendix C clearly show Fort Irwin as the front-running competitor for intervisibility matching with Qasrod Dasht.

A highly homogeneous CONUS test site/overseas site combination discovered during the conduct of the study, was FHL/South Korea. Throughout all phases of comparison: gross, statistical, and graphical, this combination showed the closest match.

Since it is doubtful that a CONUS test site/overseas site optimum combination can be routinely utilized, the concept of extrapolation of intervisibility results was developed. Extrapolation of results is desirable even for reasonably matched scenarios, although the changes are not as pronounced as for those poorly matched. The transformation equations derived from a series of least square line fits are included in Table 6. Appendix E provides graphical information showing how much validity one may place on the provided transformation equations. The Fulda Gap/FHL, Qasrod Dasht/Fort Irwin, and South Korea/FHL combinations have nicely fitting least square lines with few outliers for almost all related intervisibility statistics. The suitability of other transformation equations must be gauged on an individual basis by examination of the least square line fits.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

With reference to the objectives of this study, CONUS-OCONUS intervisibility comparisons were accomplished, although the amount of available overseas digitized terrain was limited. Transformation functions were developed which can approximate OCONUS intervisibility conditions given the results of a CONUS test. The comparison and transformation methodology provided may be applicable to larger scale studies conducting analysis of more varied overseas terrain.

In no way does this study promote the hypothesis that all operational testing of U.S. Army systems should be conducted solely at Fort Hunter Liggett and Fort Irwin, since these test sites compared most favorably with the three OCONUS sites considered. Deficiencies with this hypothesis are listed below. First, no scientific method for selection of OCONUS terrain was employed as no U.S. Army approved set of OCONUS terrain is available. Ideally, this set should be derived from an updated threat assessment of OCONUS areas of national concern, and should ultimately include an optimum mix of terrain the Army expects a particular system or unit to fight on. Second, trafficability, meteorological conditions, and differing scenarios were not considered in the results of this study. Concerning trafficability, a weapon system must physically get to where intervisibility with an enemy system exists to ensure valid results. Similarly, a system situated where intervisibility exists with an enemy force, will experience intervisibility degradations due to weather conditions. Both trafficability and meteorological conditions may vary greatly from region to region, and should be considered while conducting CONUS-OCONUS site comparisons.

Regarding the restrictions on terrain, force structure, trafficability, and meteorological conditions, Fort Hunter Liggett was found to have the closest intervisibility conditions of any current CONUS test site to Fulda Gap and the DMZ area of South Korea. The same can be said about Fort Irwin and the Qasrod Dasht region of Iran. The methodology described and enacted in this study can be expanded and utilized to first select the operational test sites with the closest intervisibility conditions, then extrapolate the results of testing to OCONUS sites of interest.

B. RECOMMENDATIONS

The following recommendations are made for further investigation and study:

1. Develop a Department of the Army approved set of overseas deployment sites on which tested systems are expected to operate. This would serve as the centralized base set of OCONUS terrain to be utilized in CONUS-OCONUS comparisons with digitized terrain.

2. Determine the correlation between critical MOEs/MOPs for a specified operational test and the intervisibility statistics digitally produced by the TRP-GSX program.

3. Develop trafficability and meteorological condition comparison procedures and transformations similar to the intervisibility comparison procedures and transformations proposed in this paper.

4. Combine intervisibility, trafficability, and meteorological results to determine closest CONUS-OCONUS site comparisons, and to facilitate extrapolation of results from CONUS sites to different operational sites.

5. Conduct experiments on the extrapolation of results concept. For experiments conducted at two sites, attempt to transform the results of each site to the other. Once this has been accomplished, compare these results with the computer simulated transformation results described in this study.

APPENDIX A

EMPIRICAL CDF PLOTS

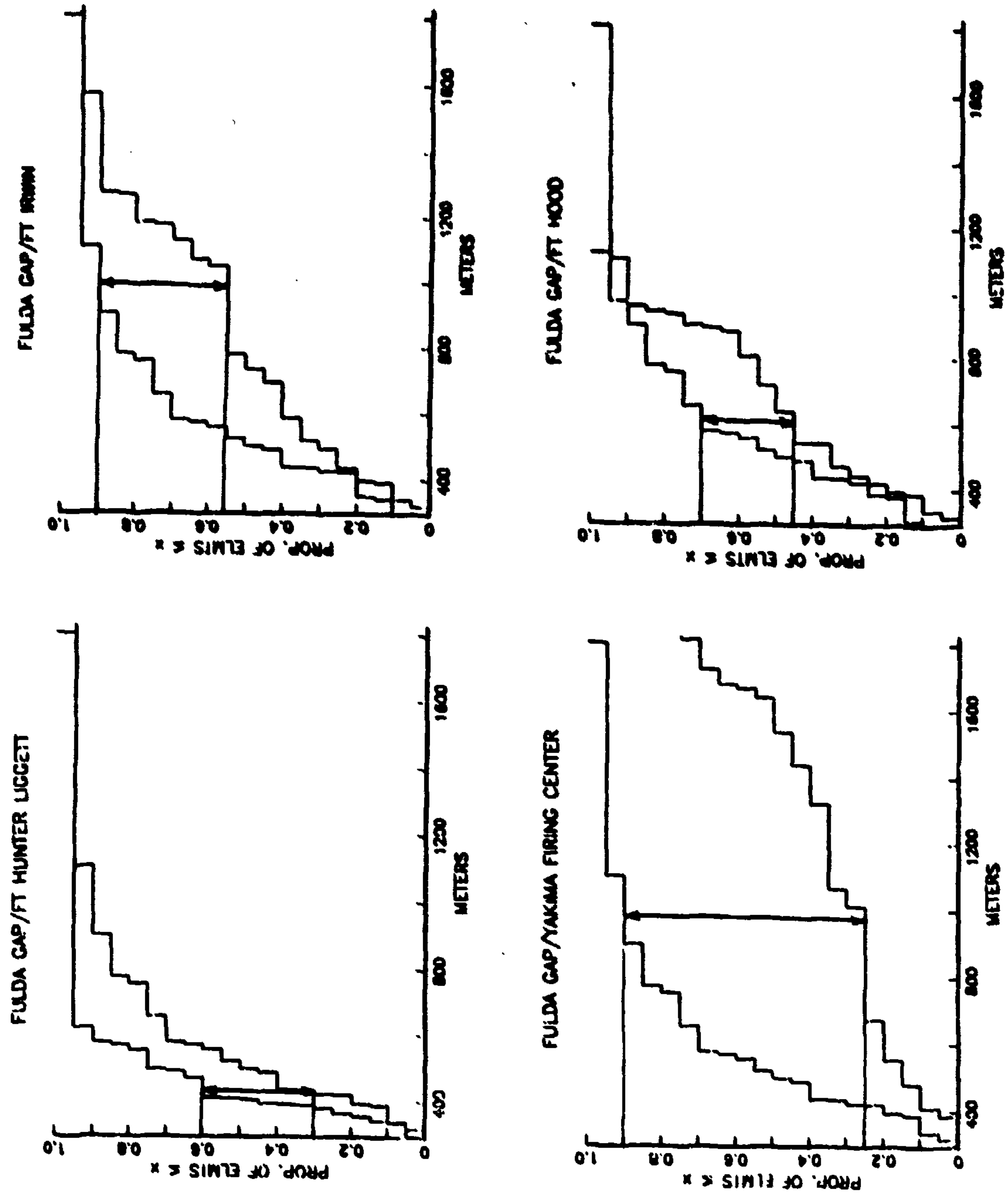


Figure A.1 Empirical In-View CDF Plots

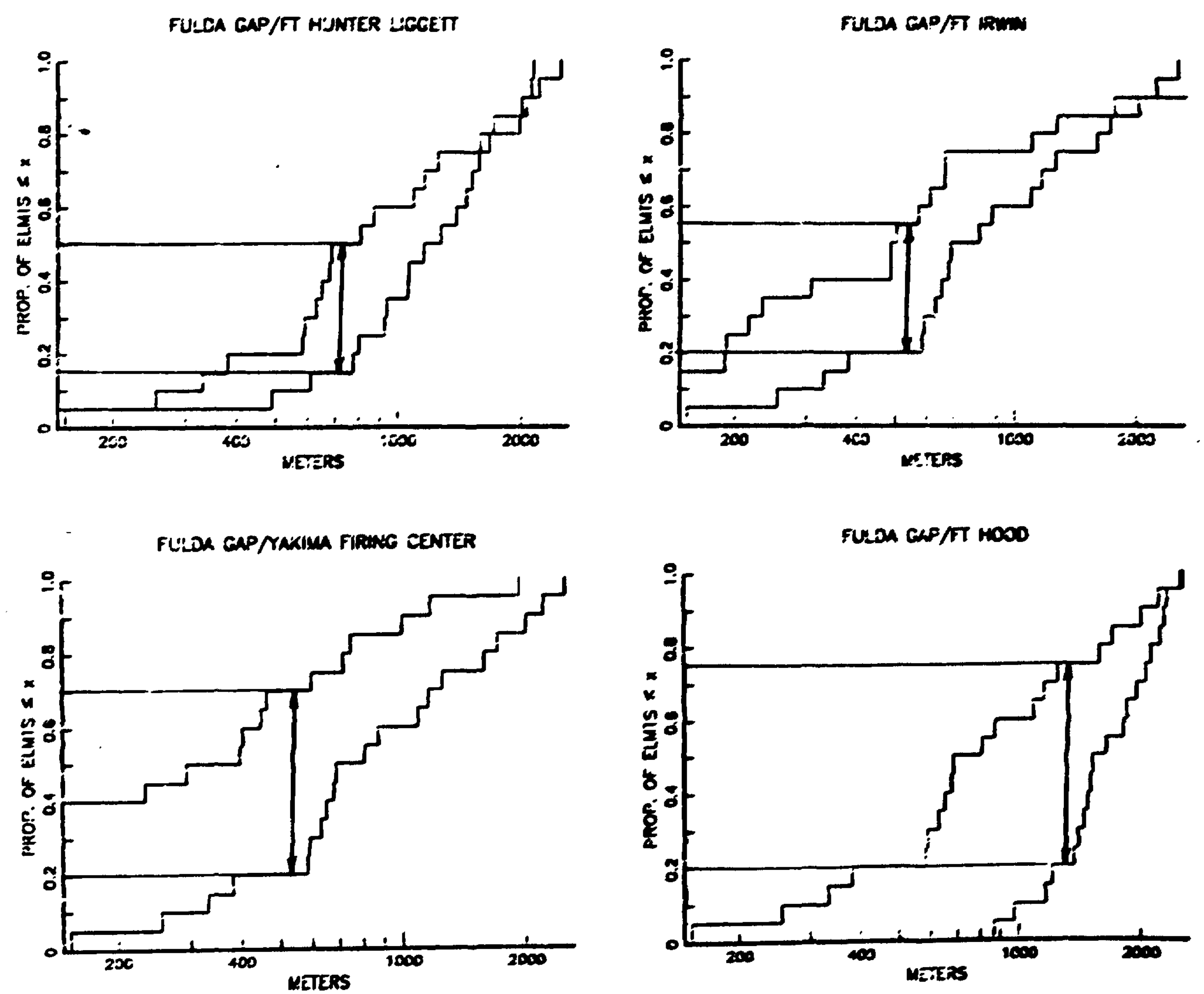


Figure A.2 Empirical Out-Of-View CDF Plots

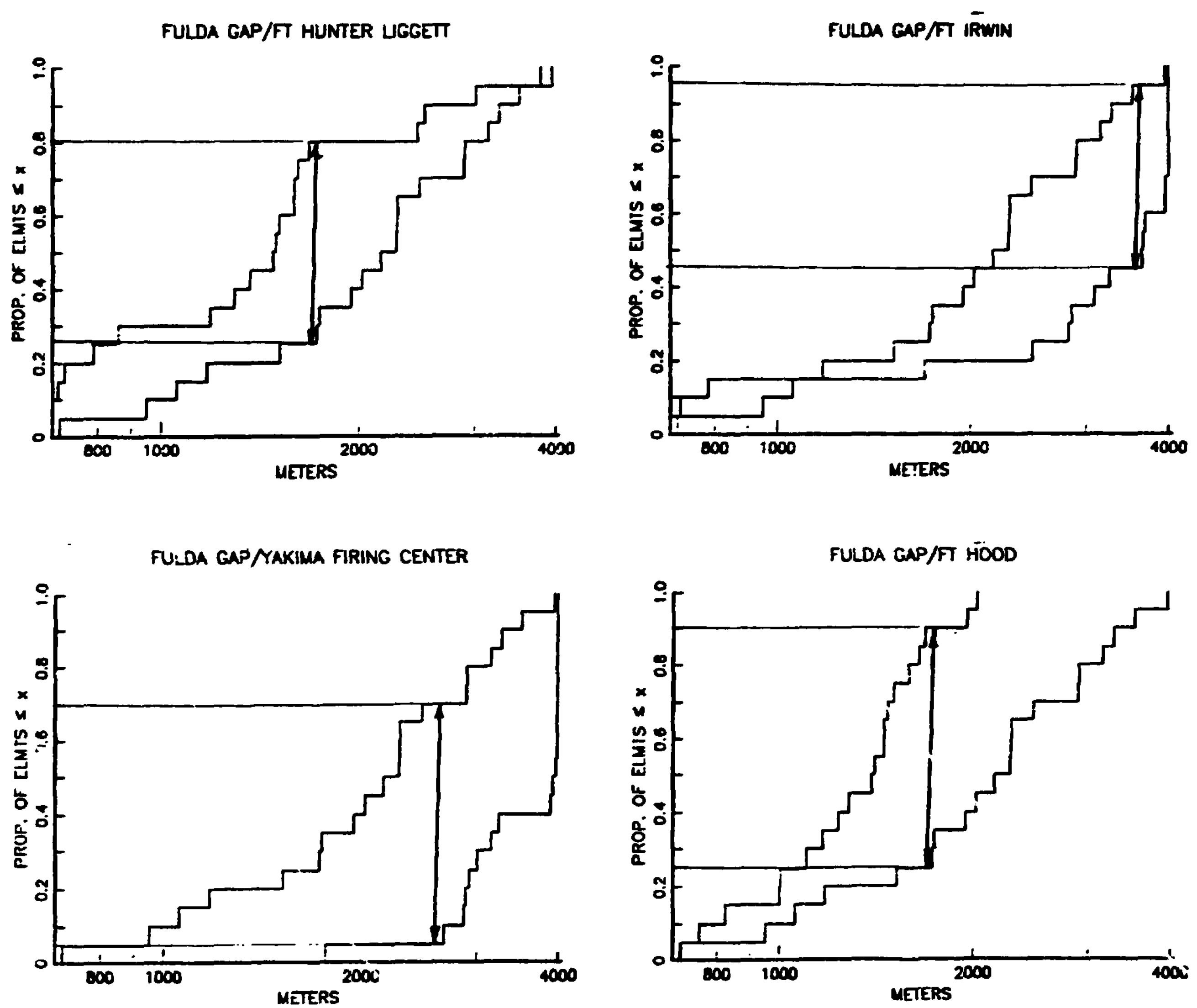


Figure A.3 Empirical First Opening RG CDF Plots

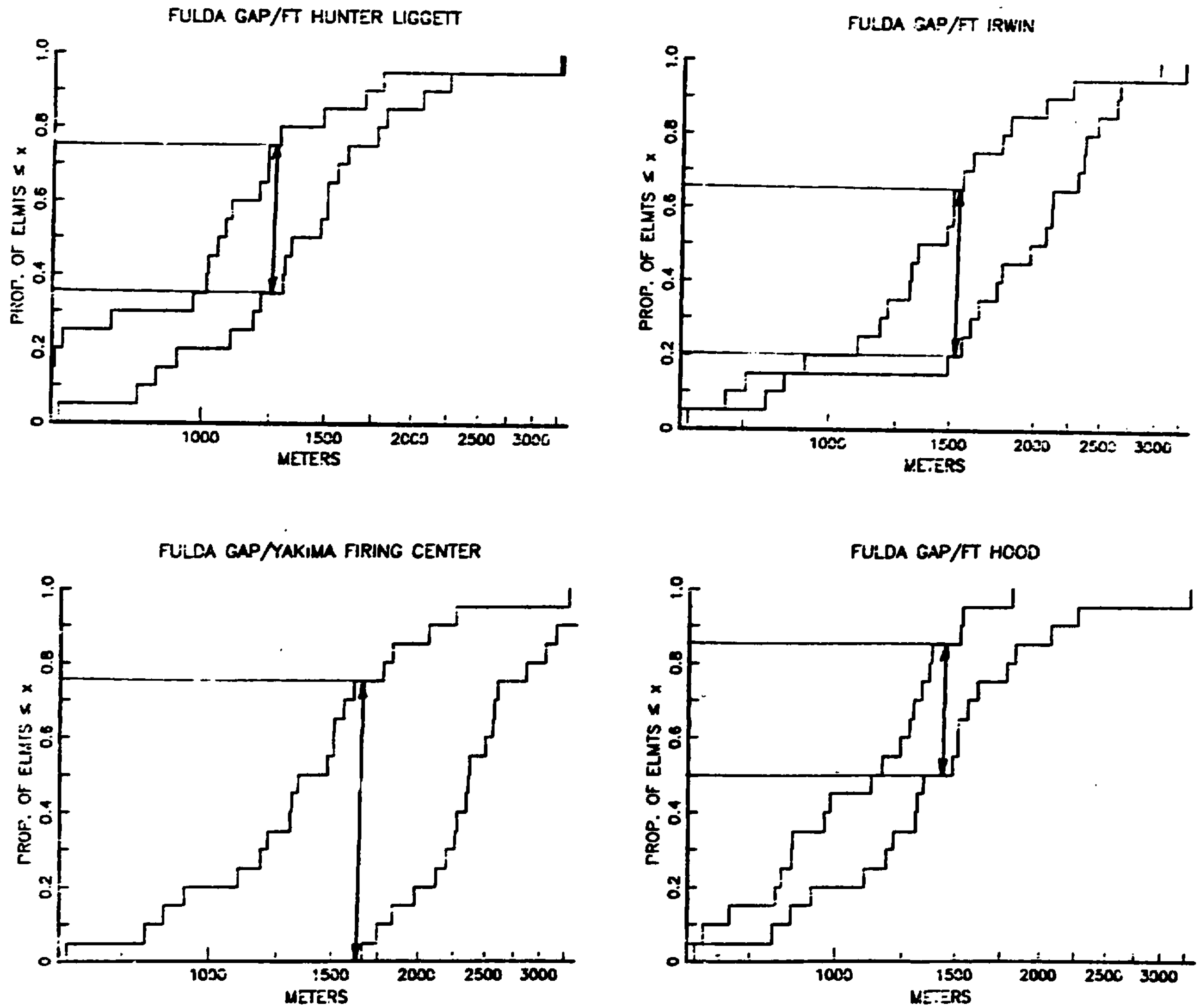


Figure A.4 Empirical Expected Opening RG CDF Plots

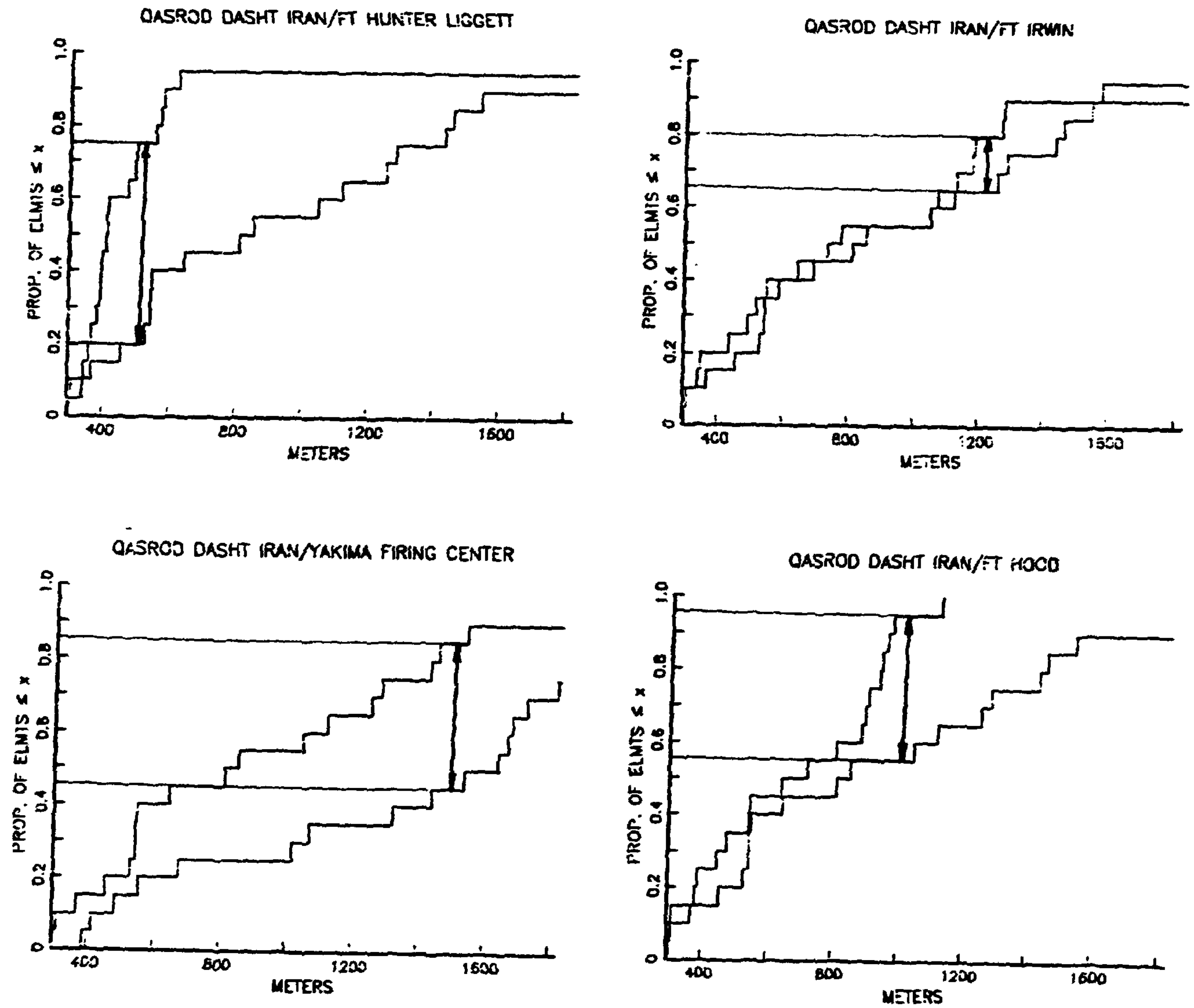


Figure A.5 Empirical In-View CDF Plots

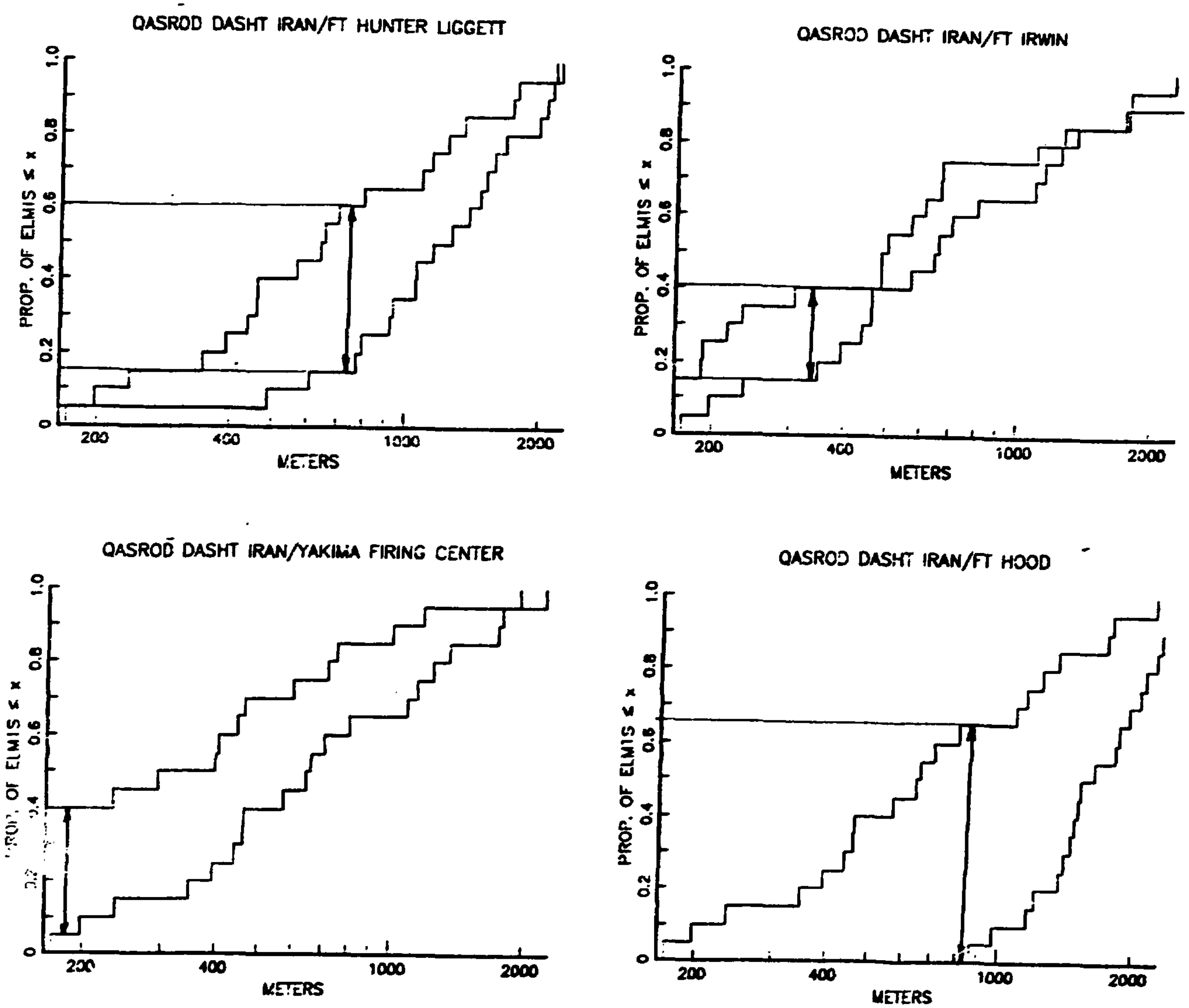


Figure A.6. Empirical Out-Of-View CDF PLots

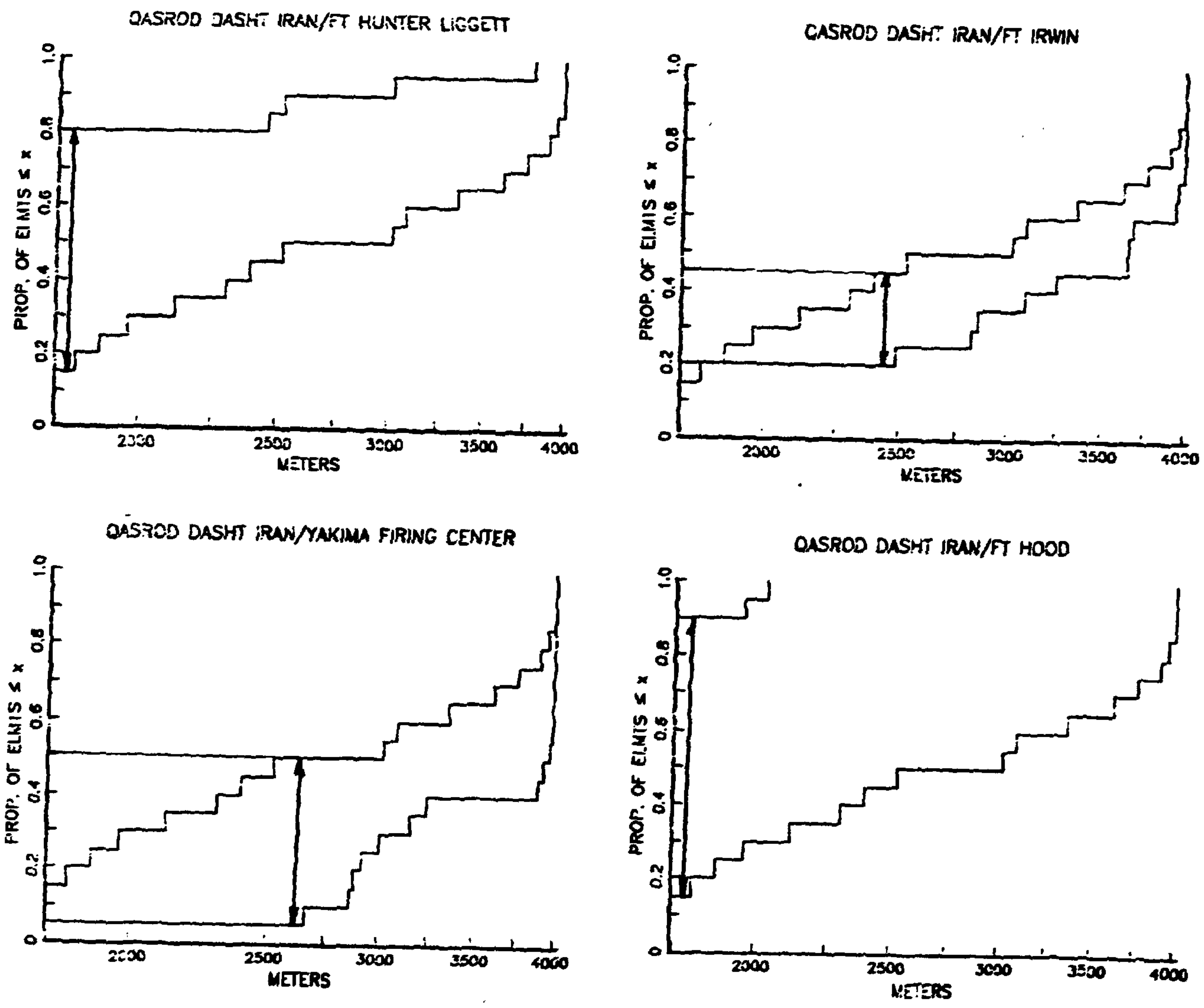


Figure A.7 Empirical First Opening RG CDF Plots

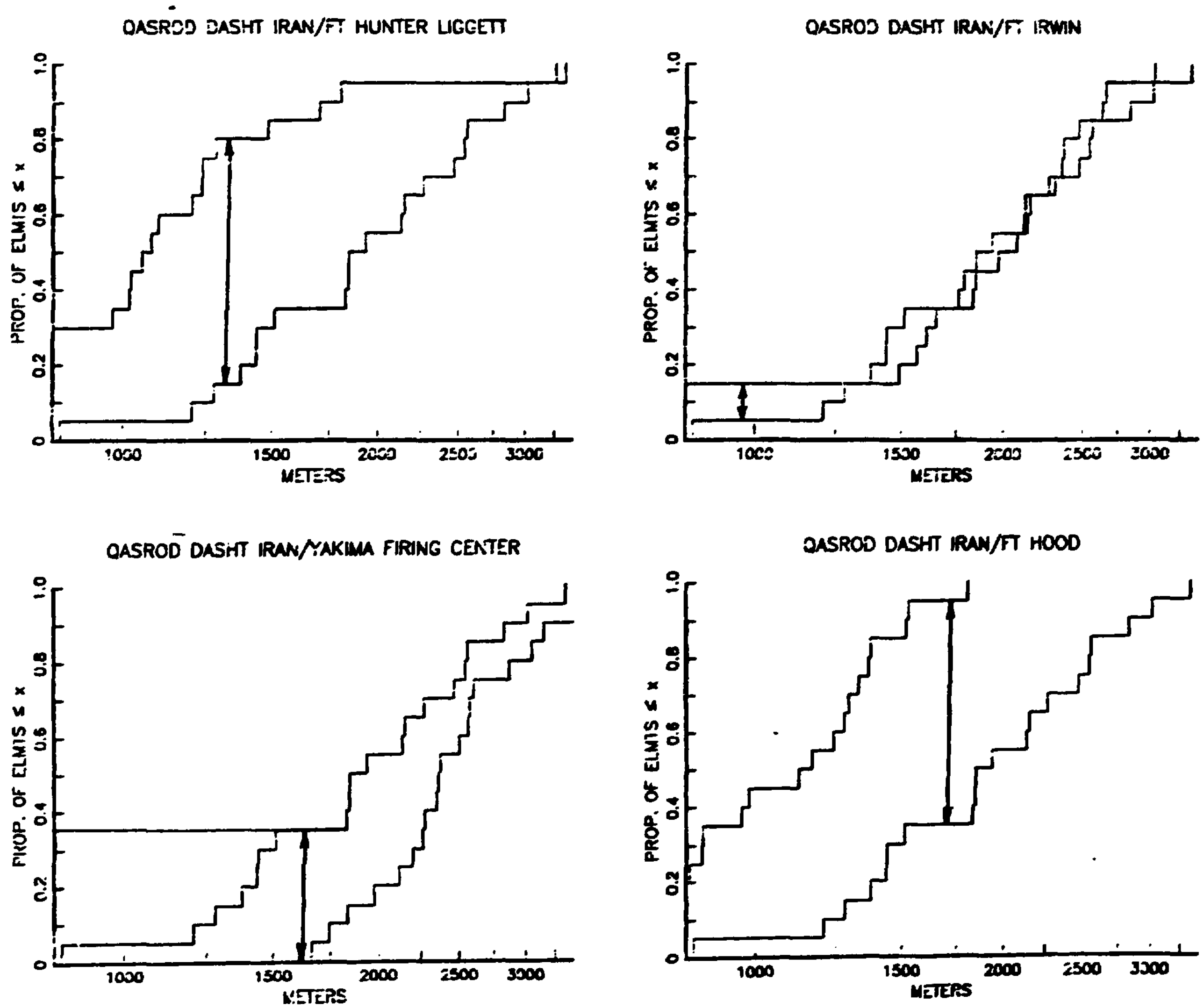


Figure A.8 Empirical Expected Opening RG CDF Plots

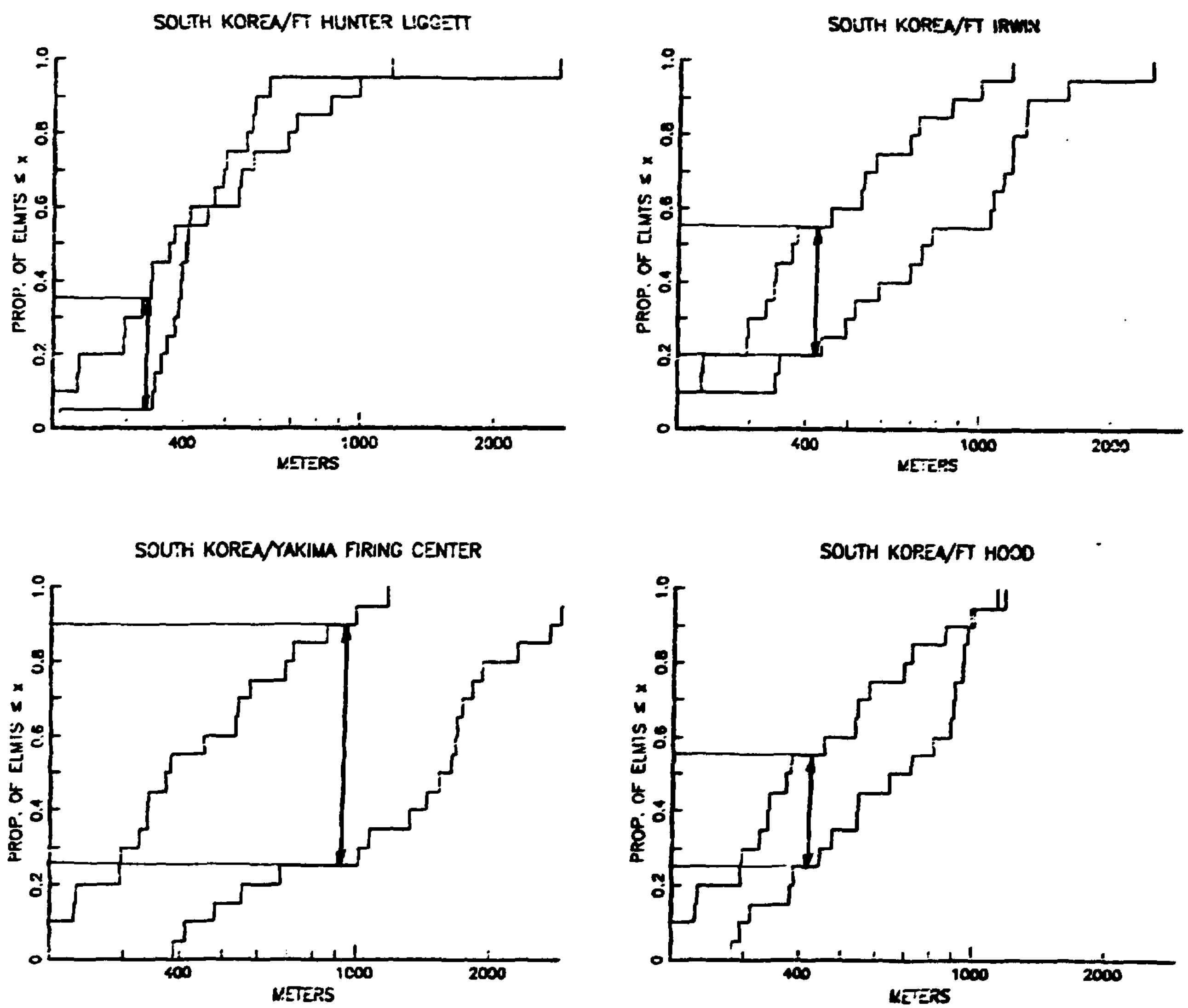


Figure A. 9 Empirical In-View CDF Plots

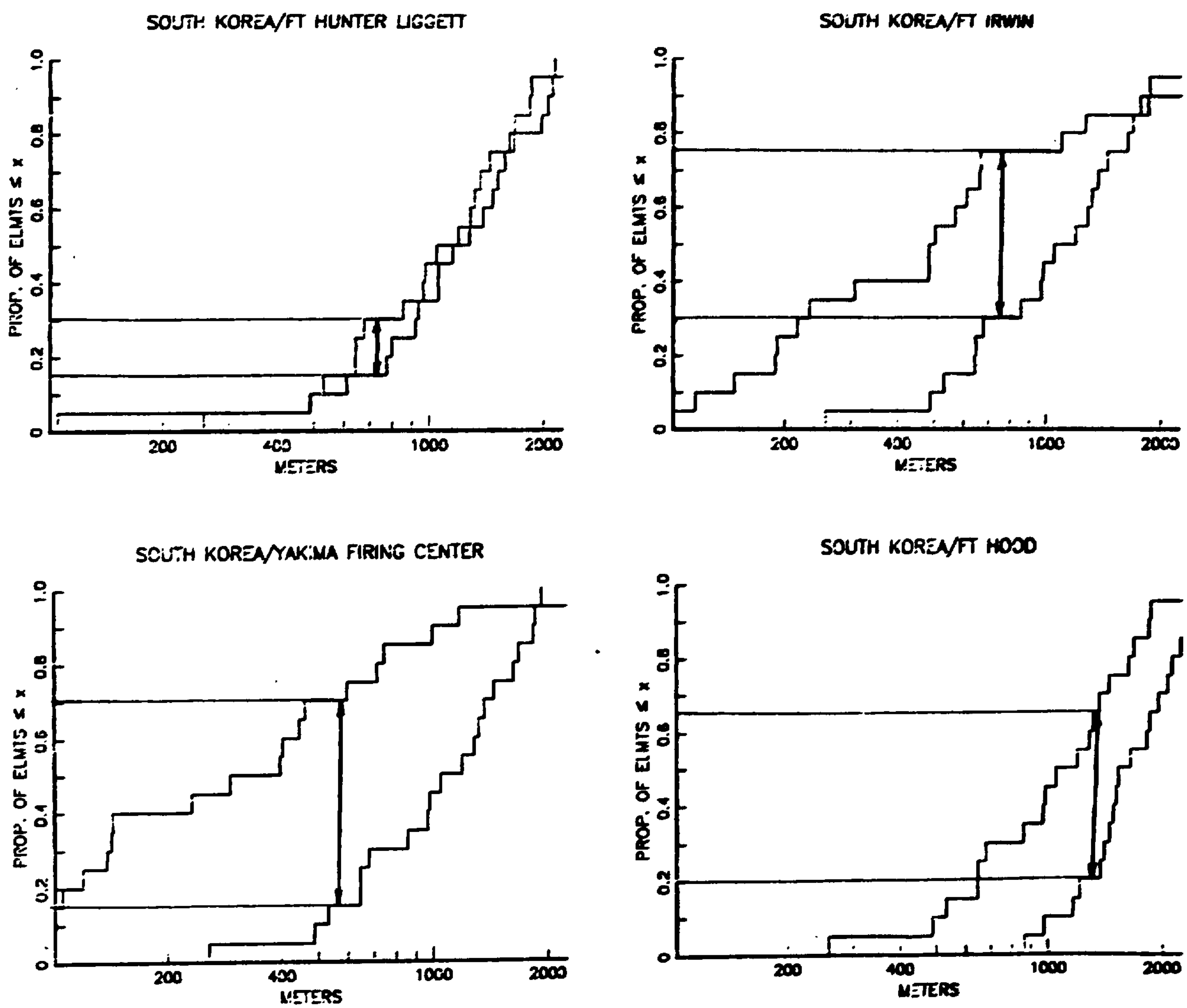


Figure A.10 Empirical Out-Of-View CDF Plots

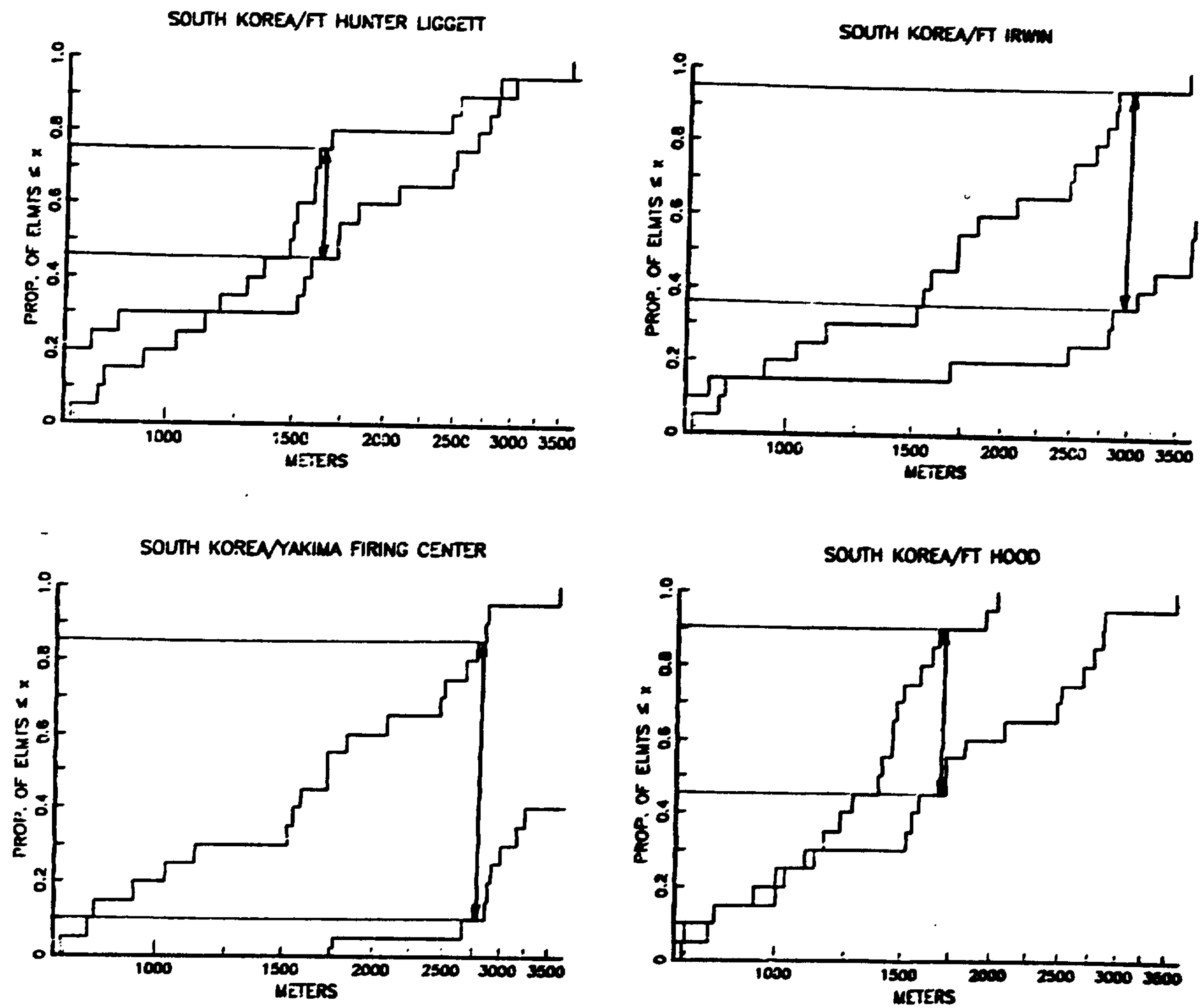


Figure A.11 Empirical First Opening RG CDF Plots

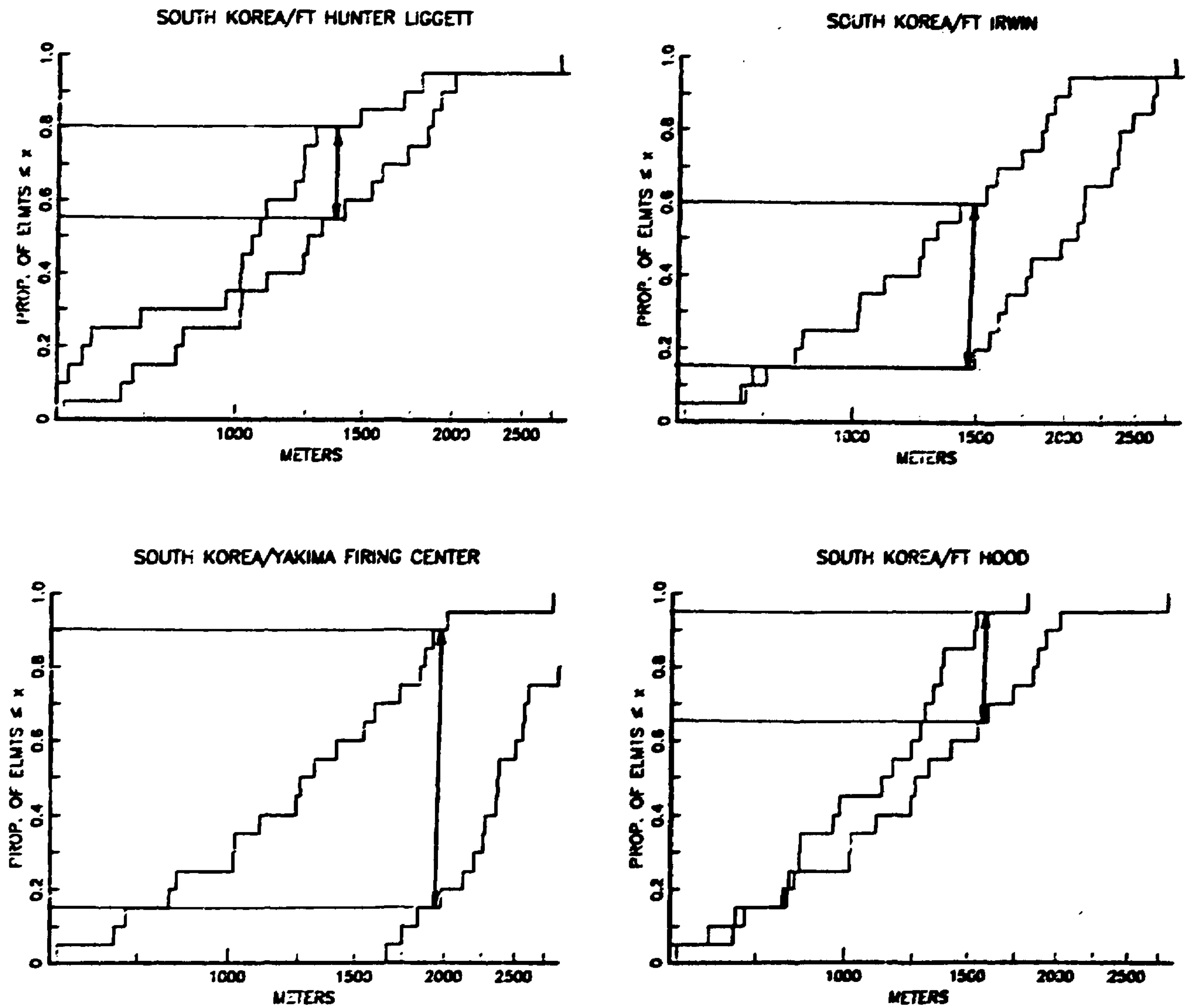


Figure A.12 Empirical Expected Opening RG CDF Plots

APPENDIX B

COMPARISONS OF FULDA GAP AND CONUS TEST SITES

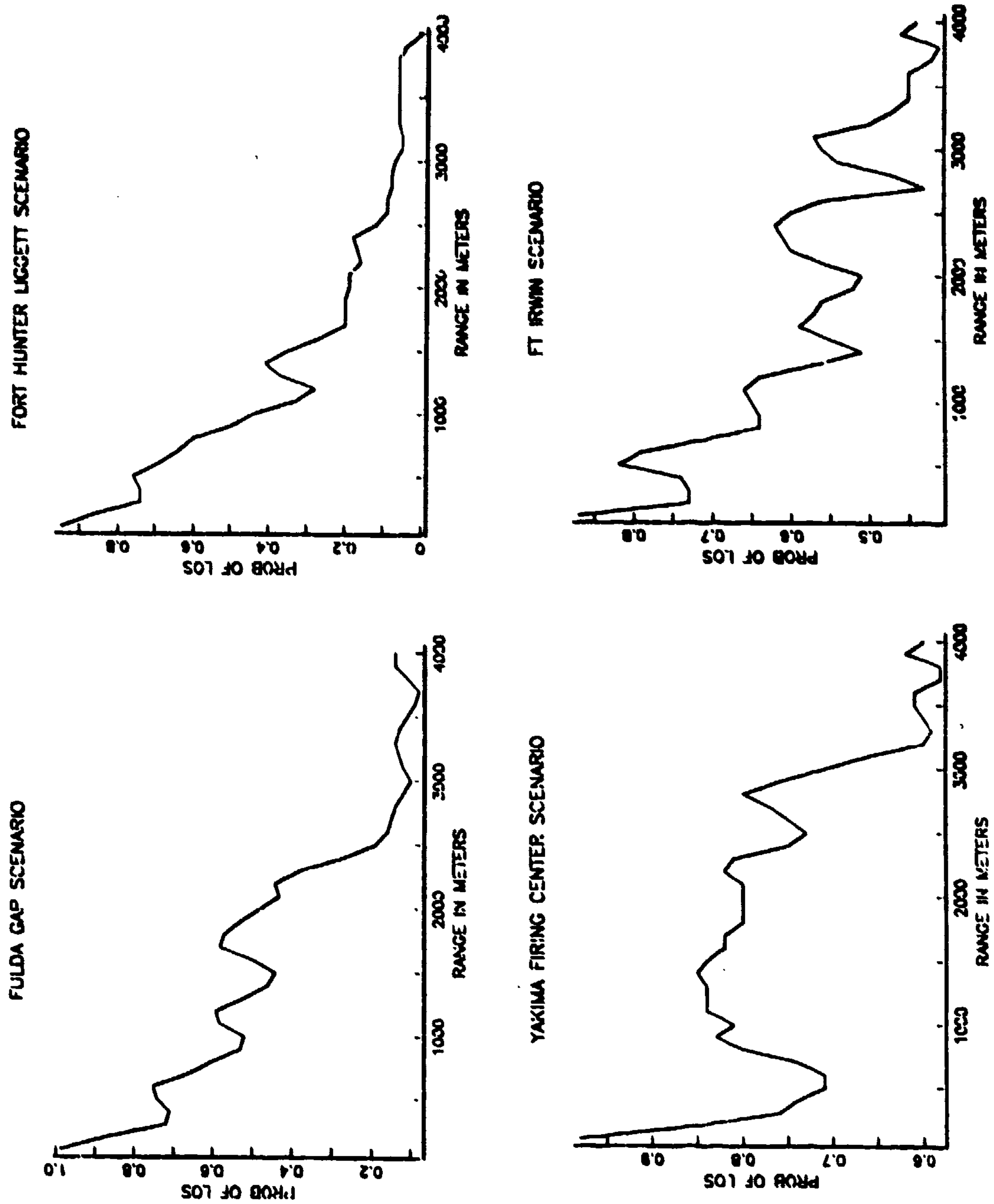


Figure B.1 Probability of Line of Sight Distributions

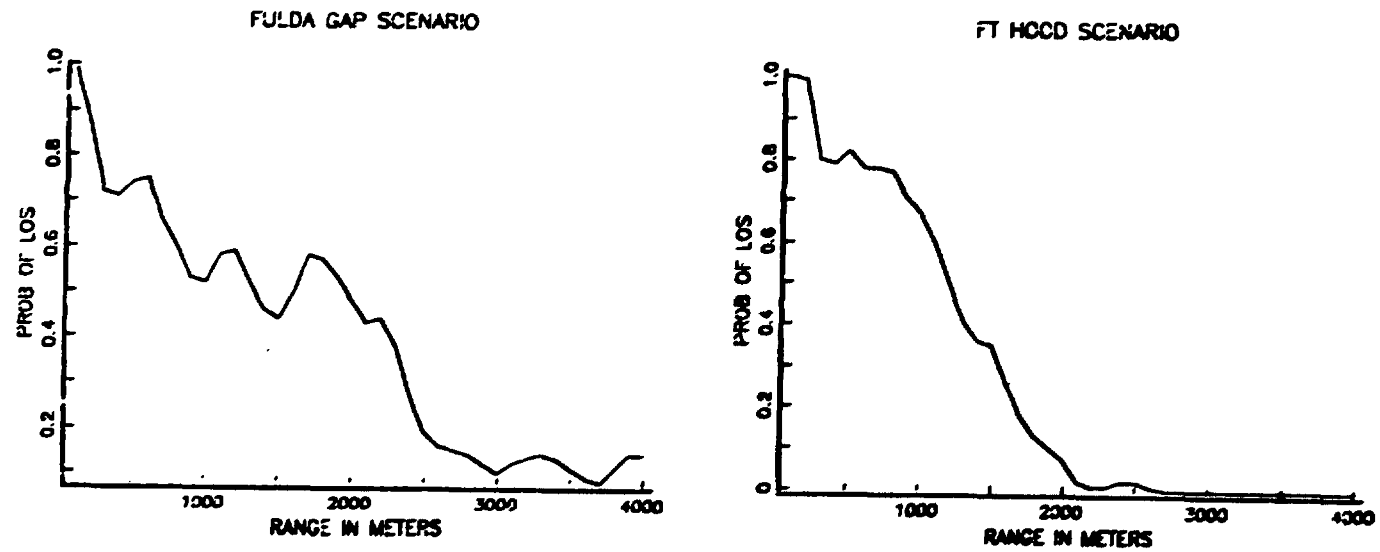


Figure B.2 Probability of Line of Sight Distributions

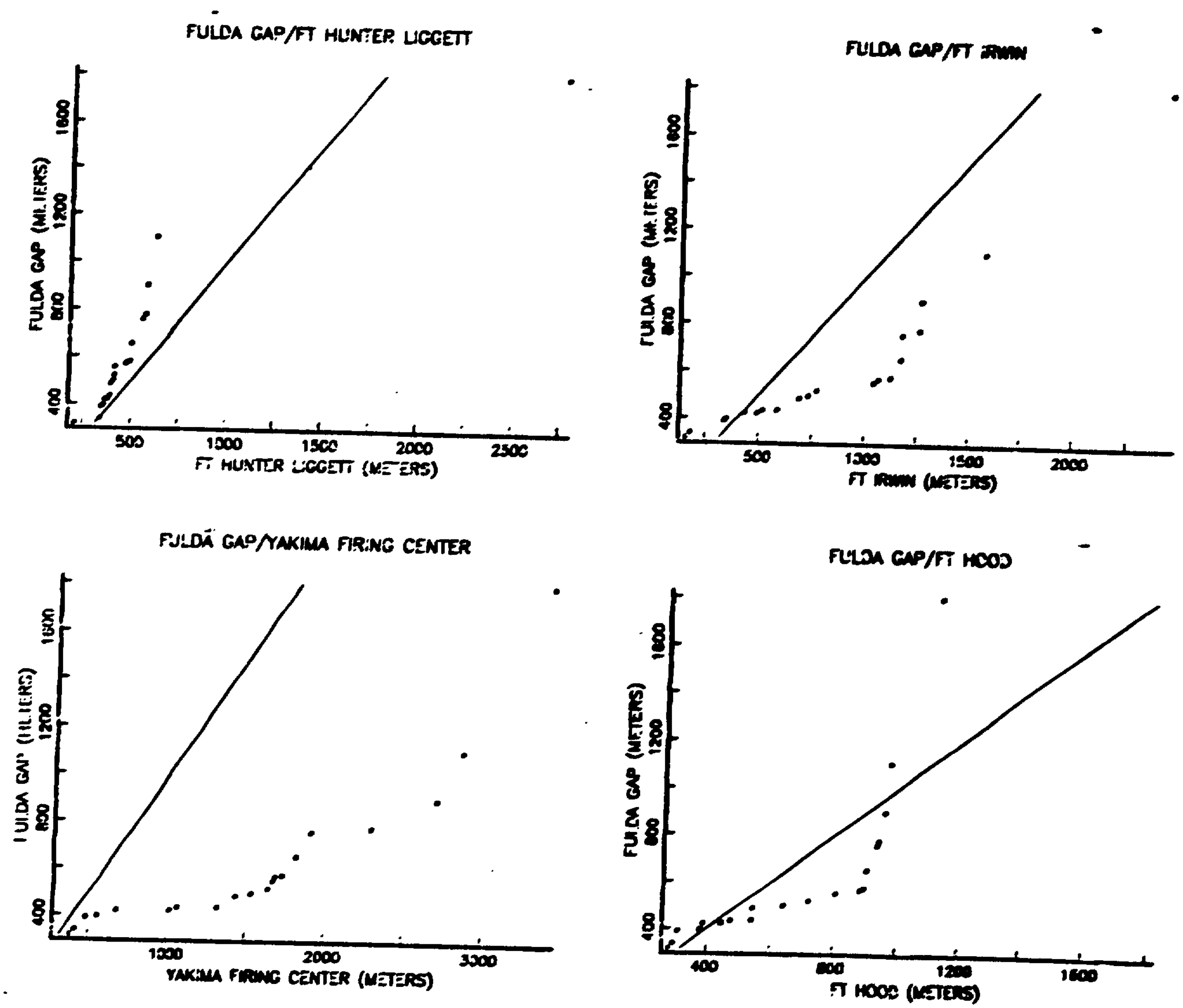


Figure B.3 Empirical Q-Q Plot of Mean In-View Segments

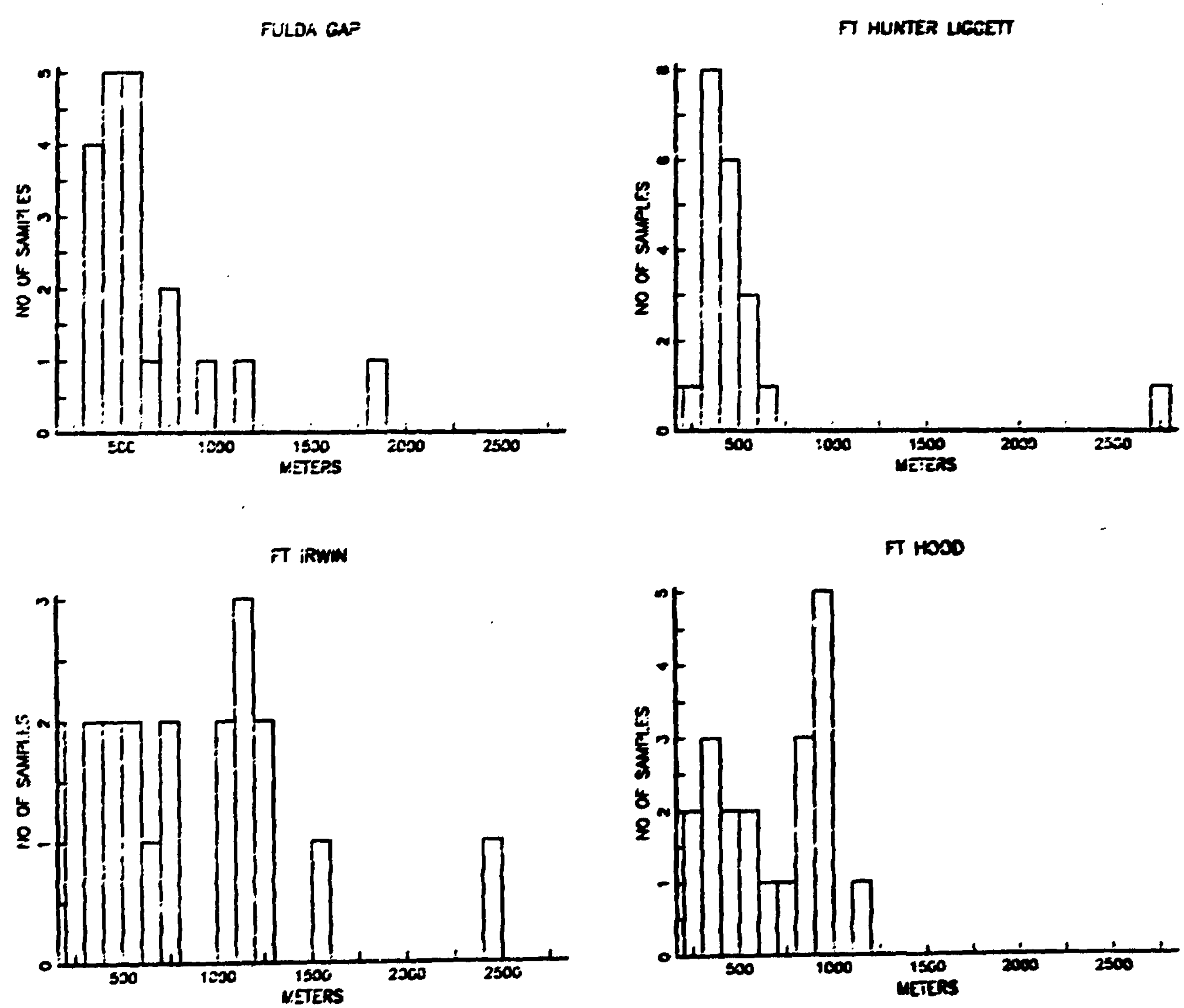


Figure B.4 Comparison of Mean In-View Segments

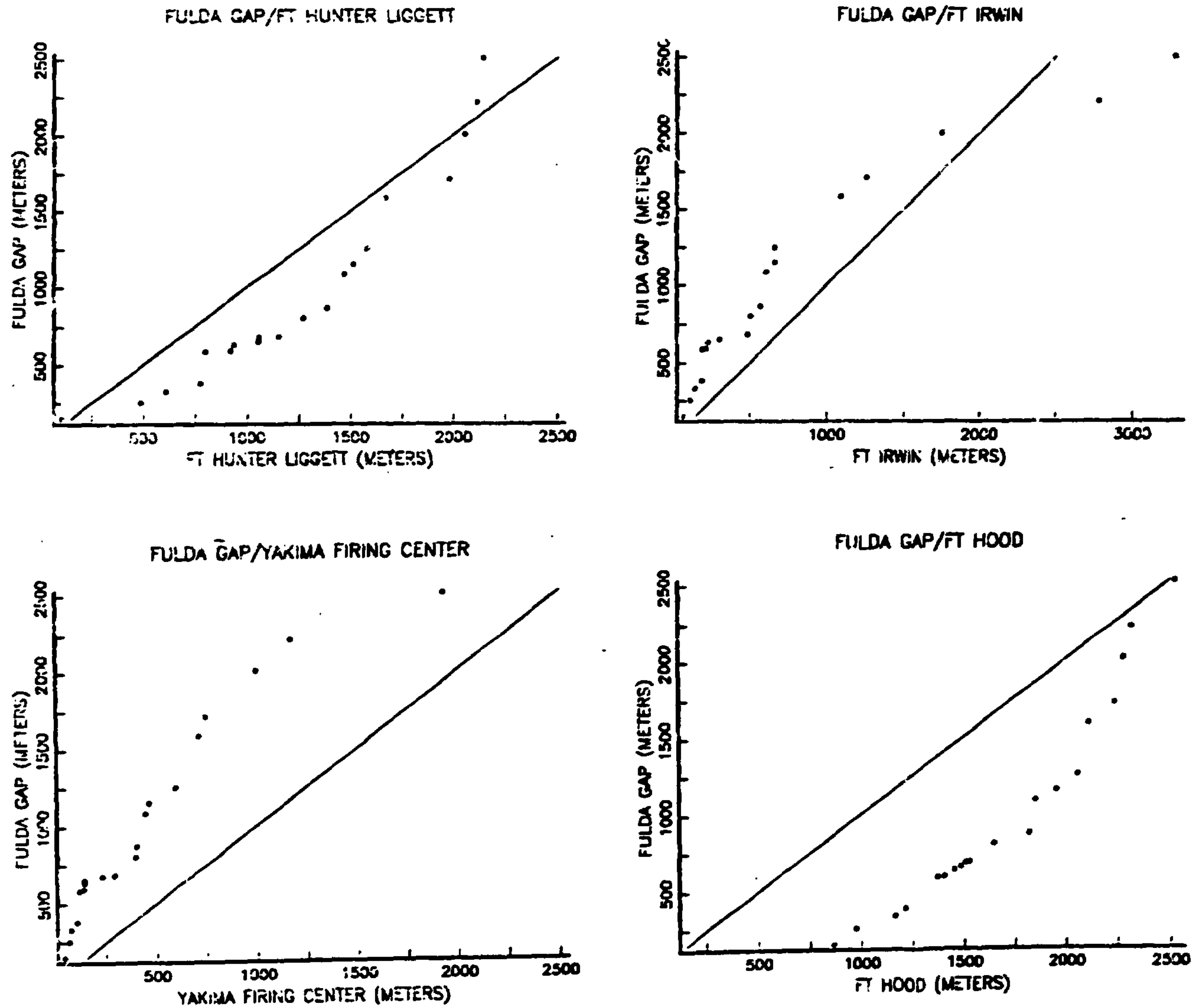


Figure B.5 Empirical Q-Q Plot of Mean Out-Of-View Segments

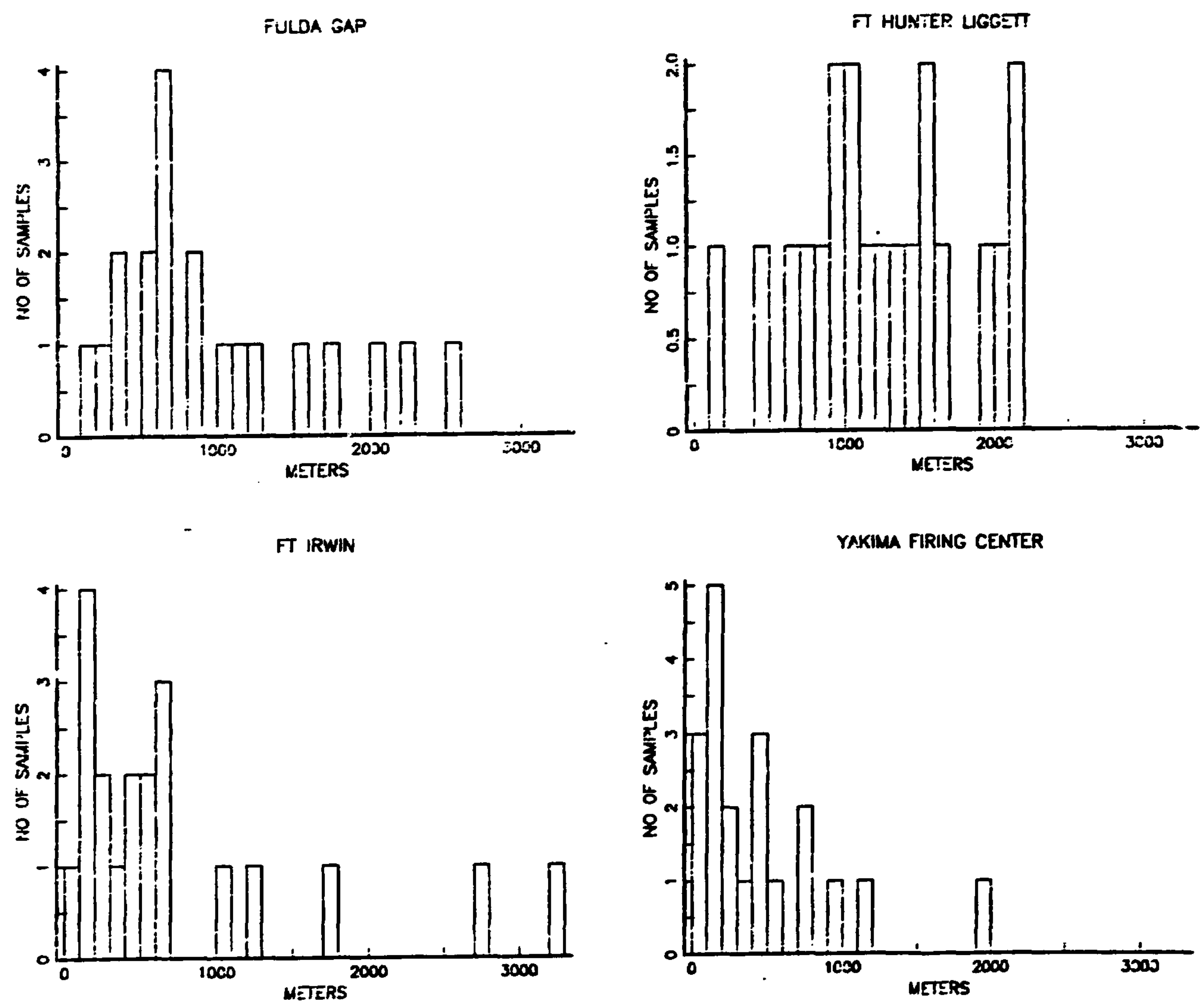


Figure B.6 Comparison of Mean Out-Of-View Segments

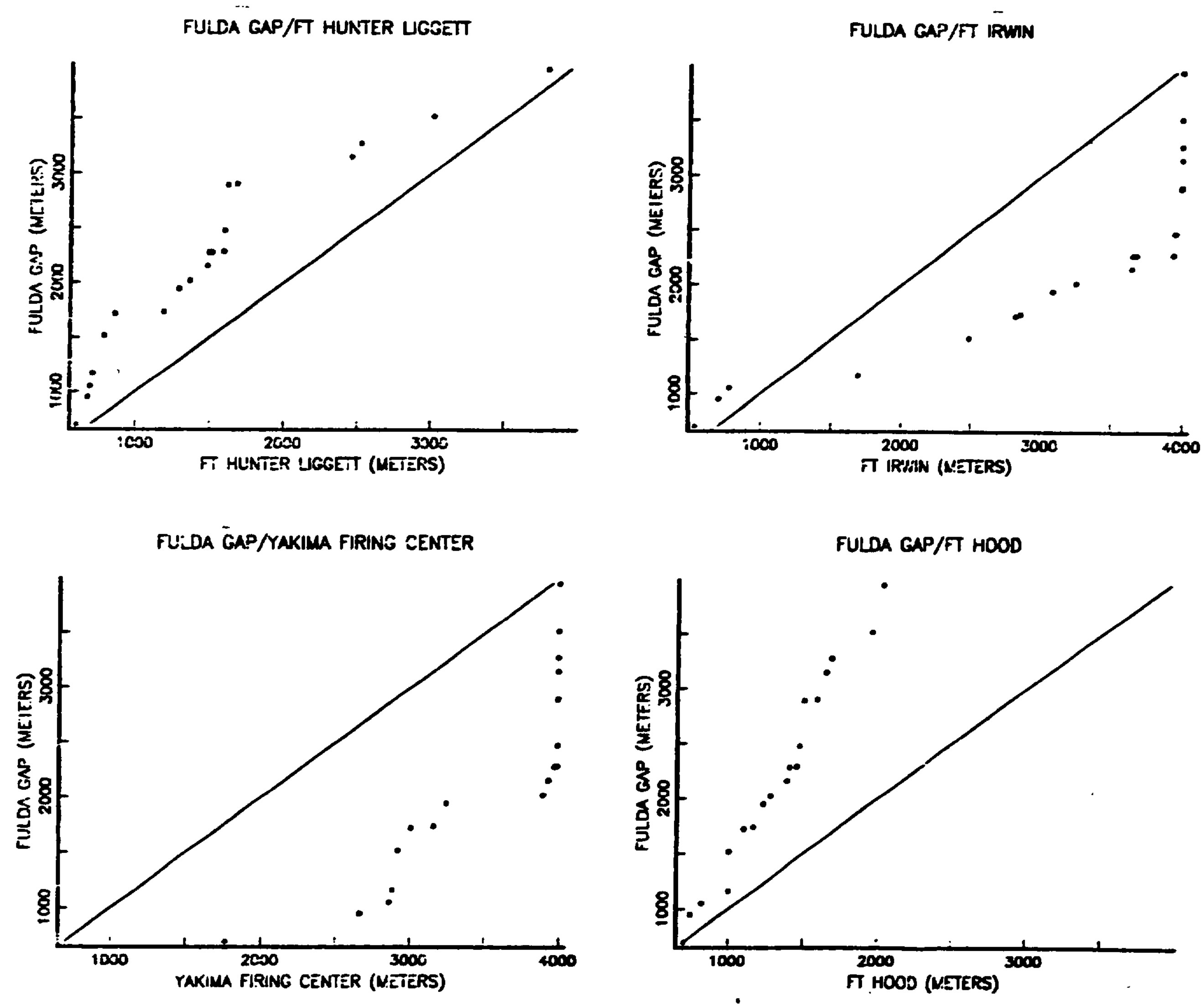


Figure B.7 Empirical Q-Q Plot of Mean First Opening Range

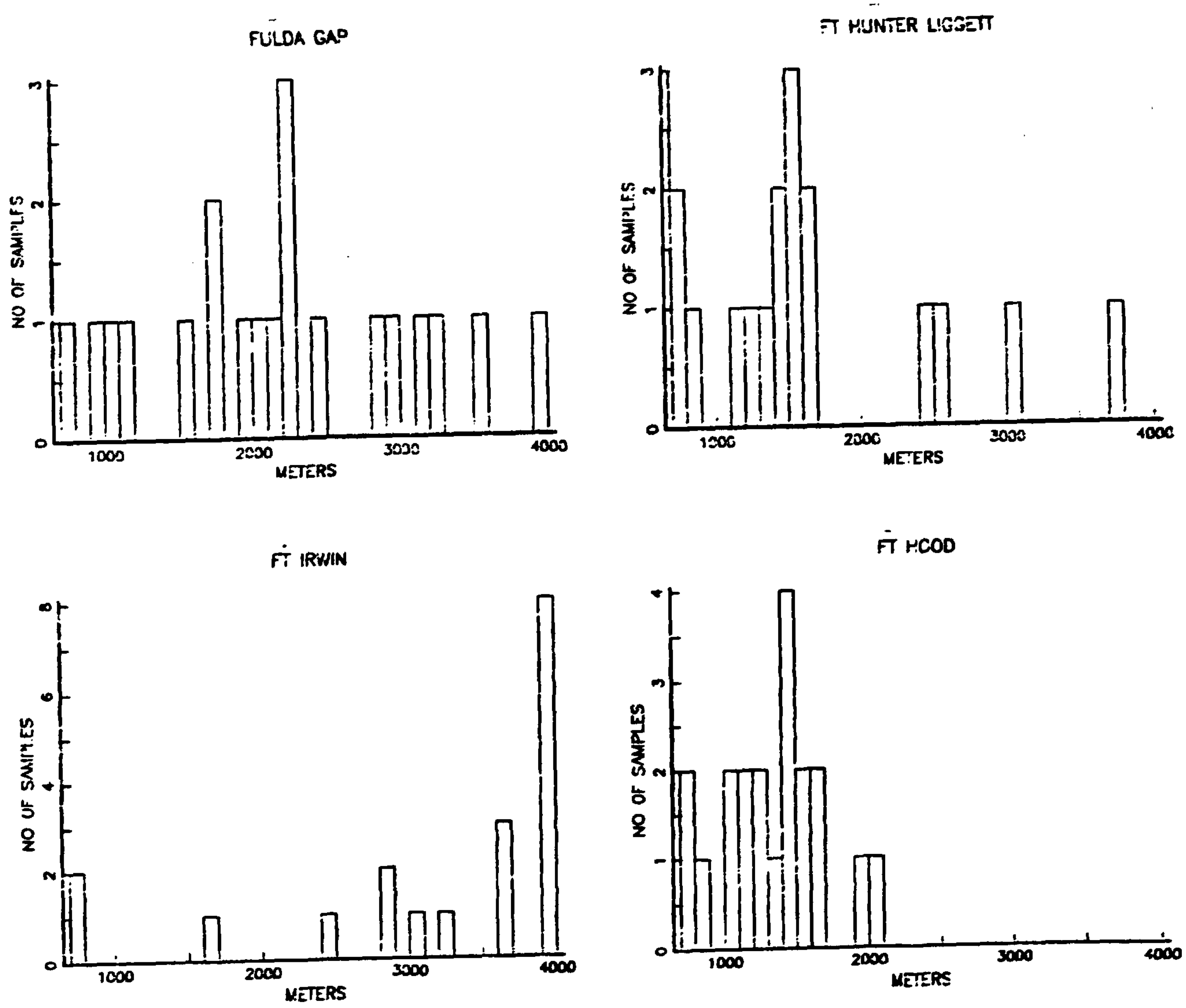


Figure B.8 Comparison of Mean First Opening Range

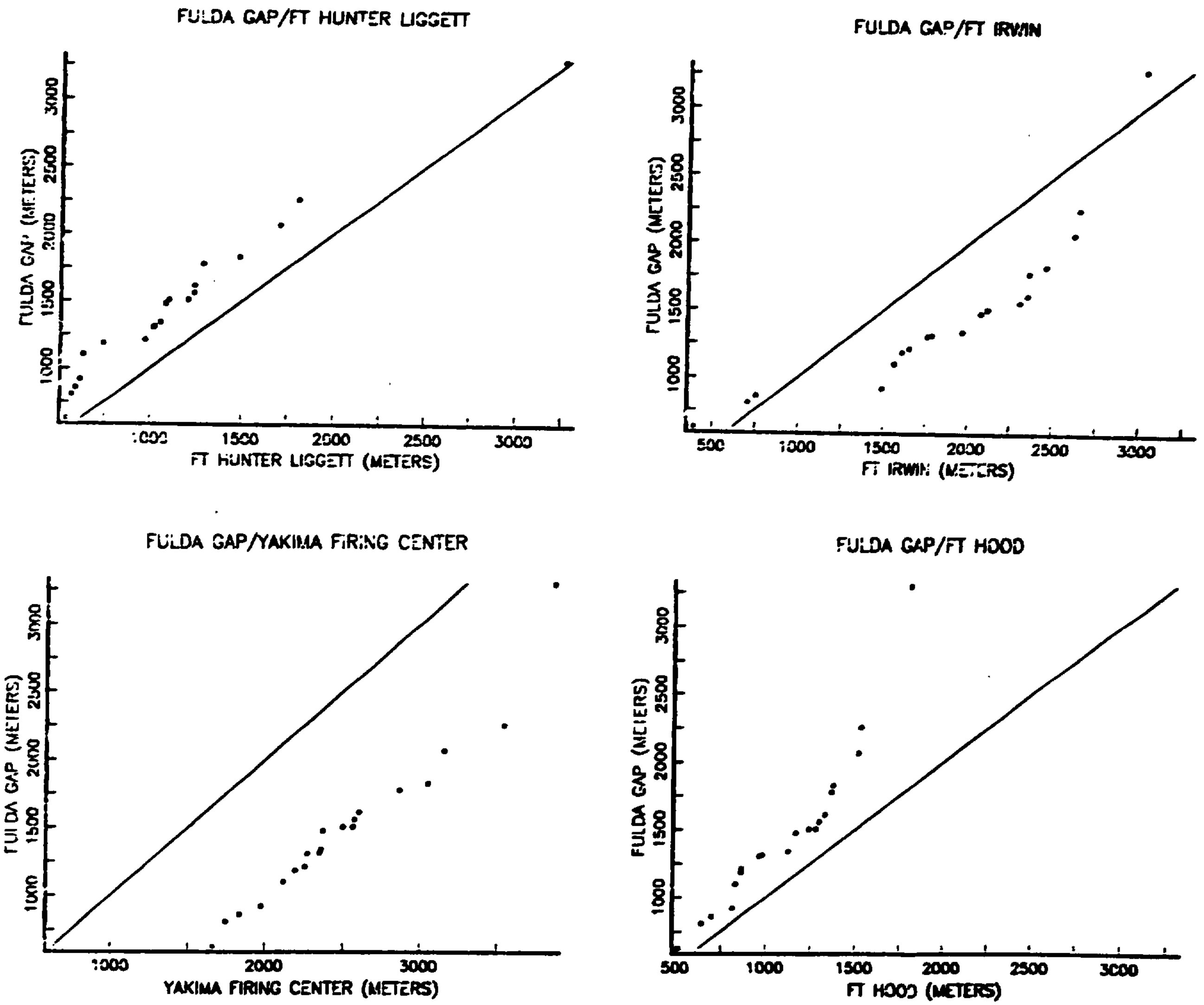


Figure B.9 Empirical Q-Q Plot of Mean Expected Opening Range

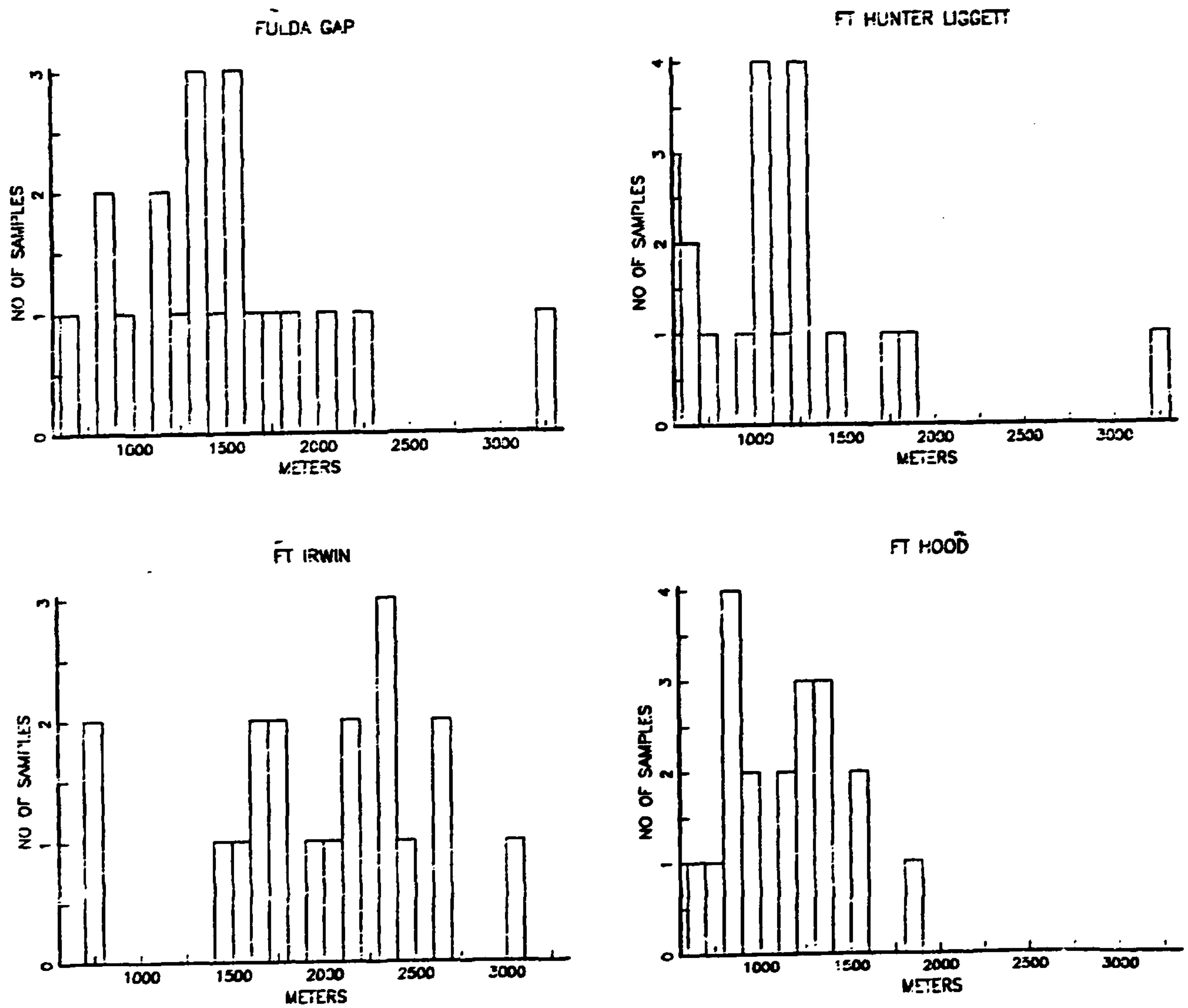


Figure B.10 Comparison of Mean Expected Opening Range

APPENDIX C

COMPARISONS OF QASROD DASHT, IRAN AND CONUS TEST SITES

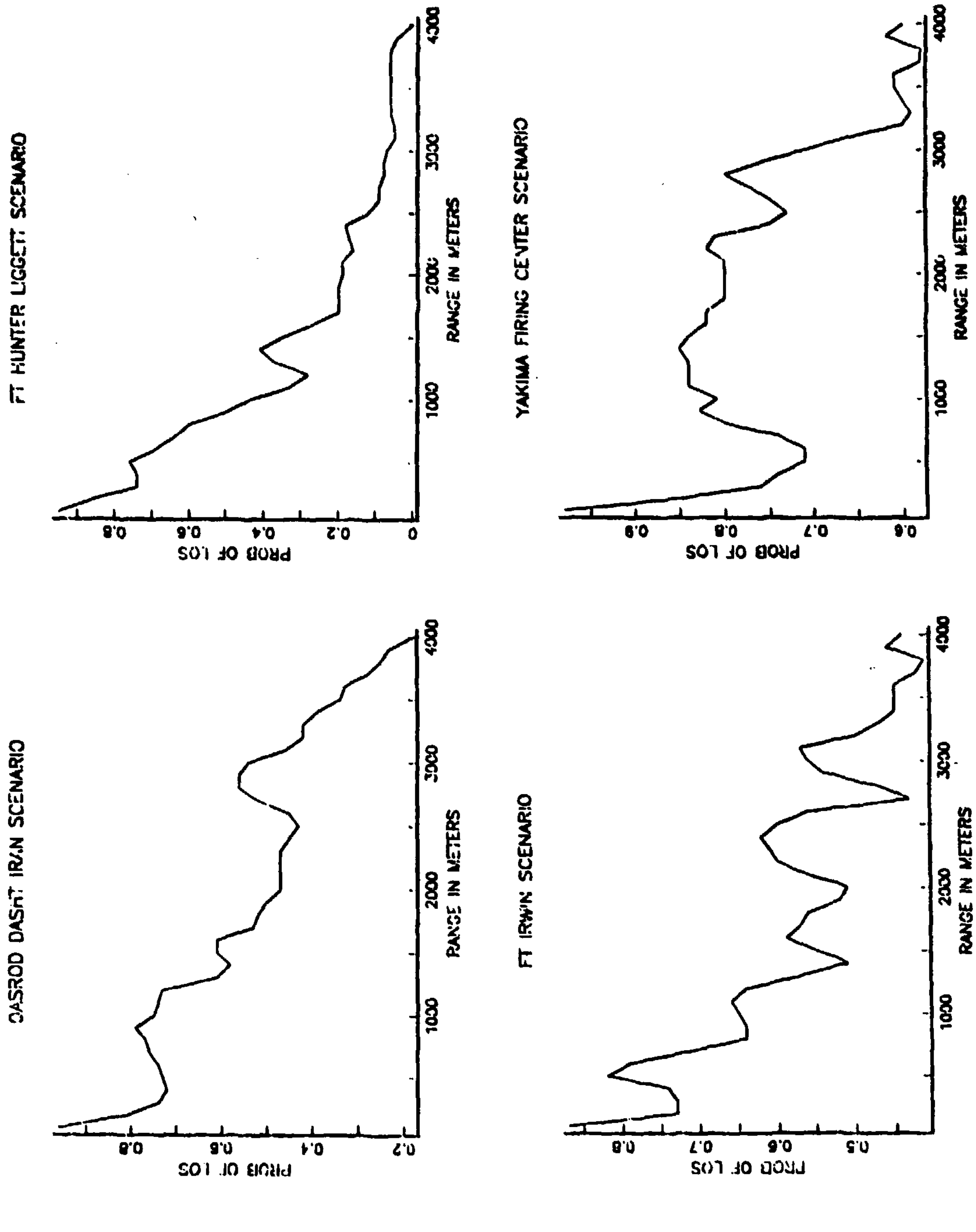


Figure C.1 Probability of Line of Sight Distributions

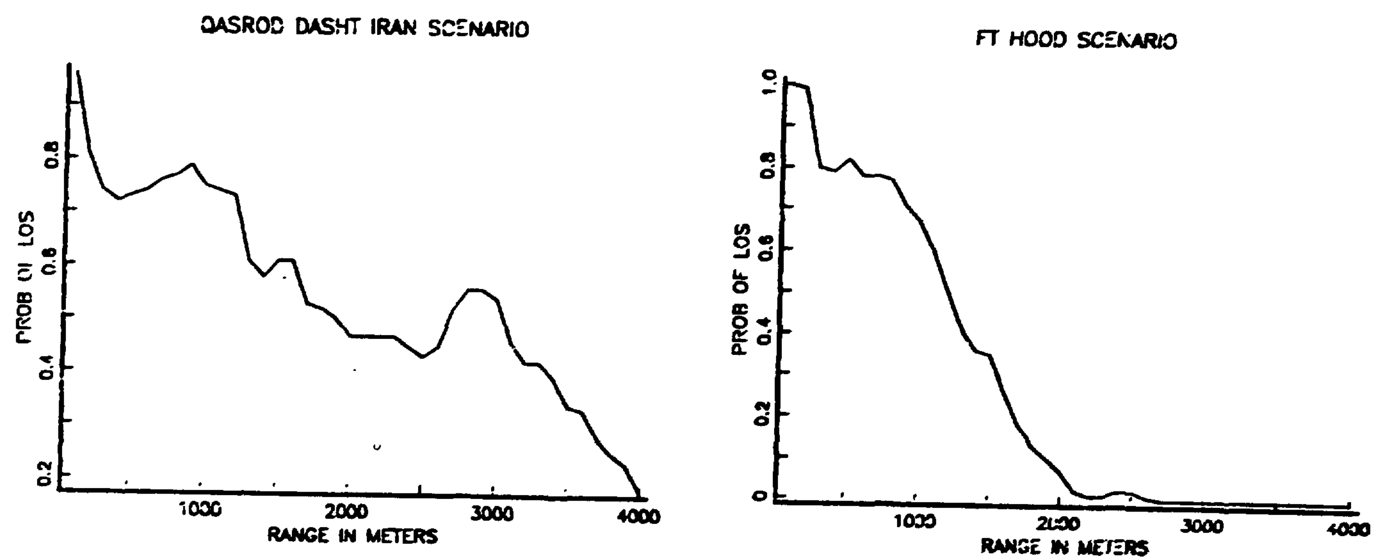


Figure C.2 Probability of Line of Sight Distributions

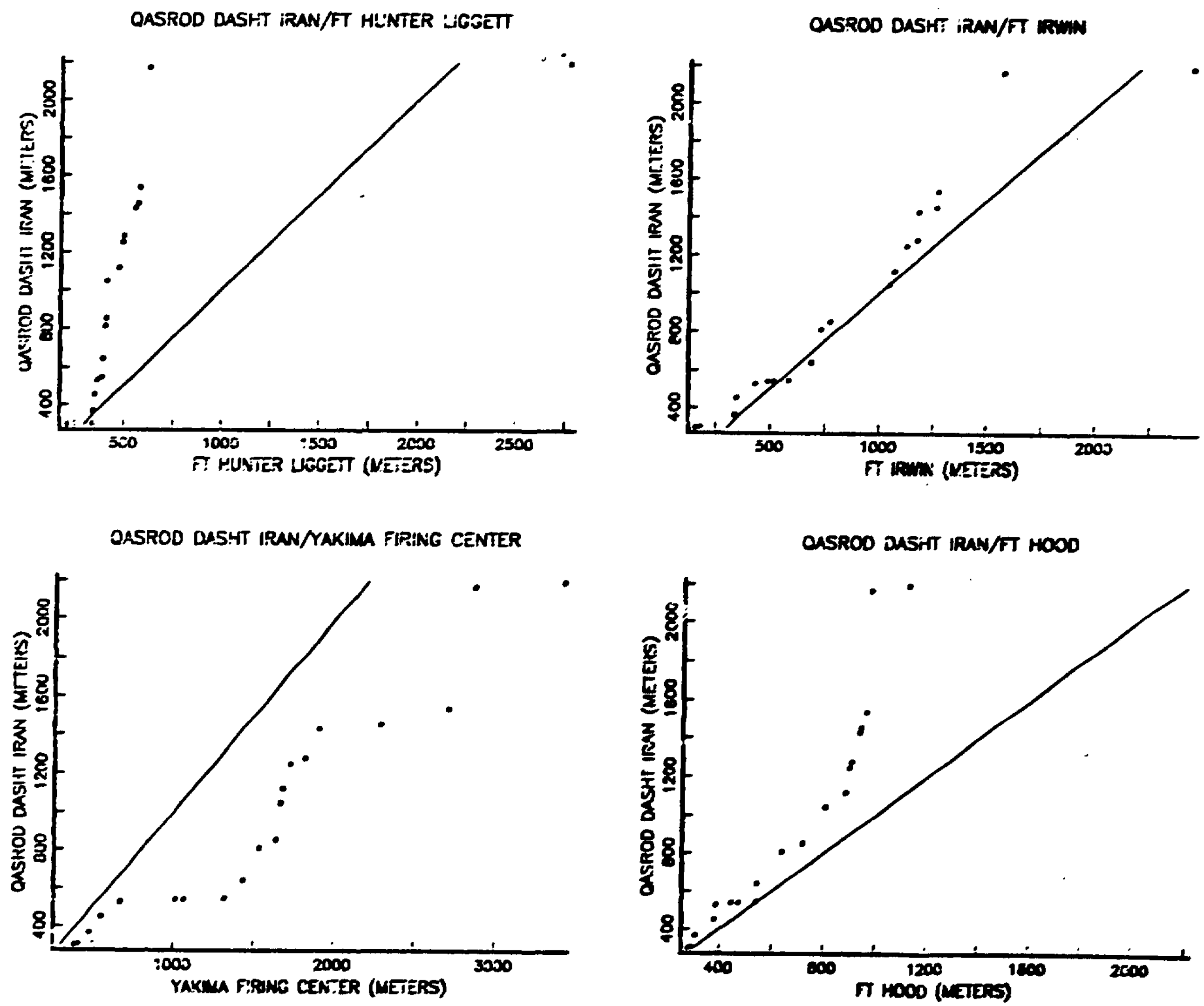


Figure C.3 Empirical Q-Q Plot of Mean In-View Segments

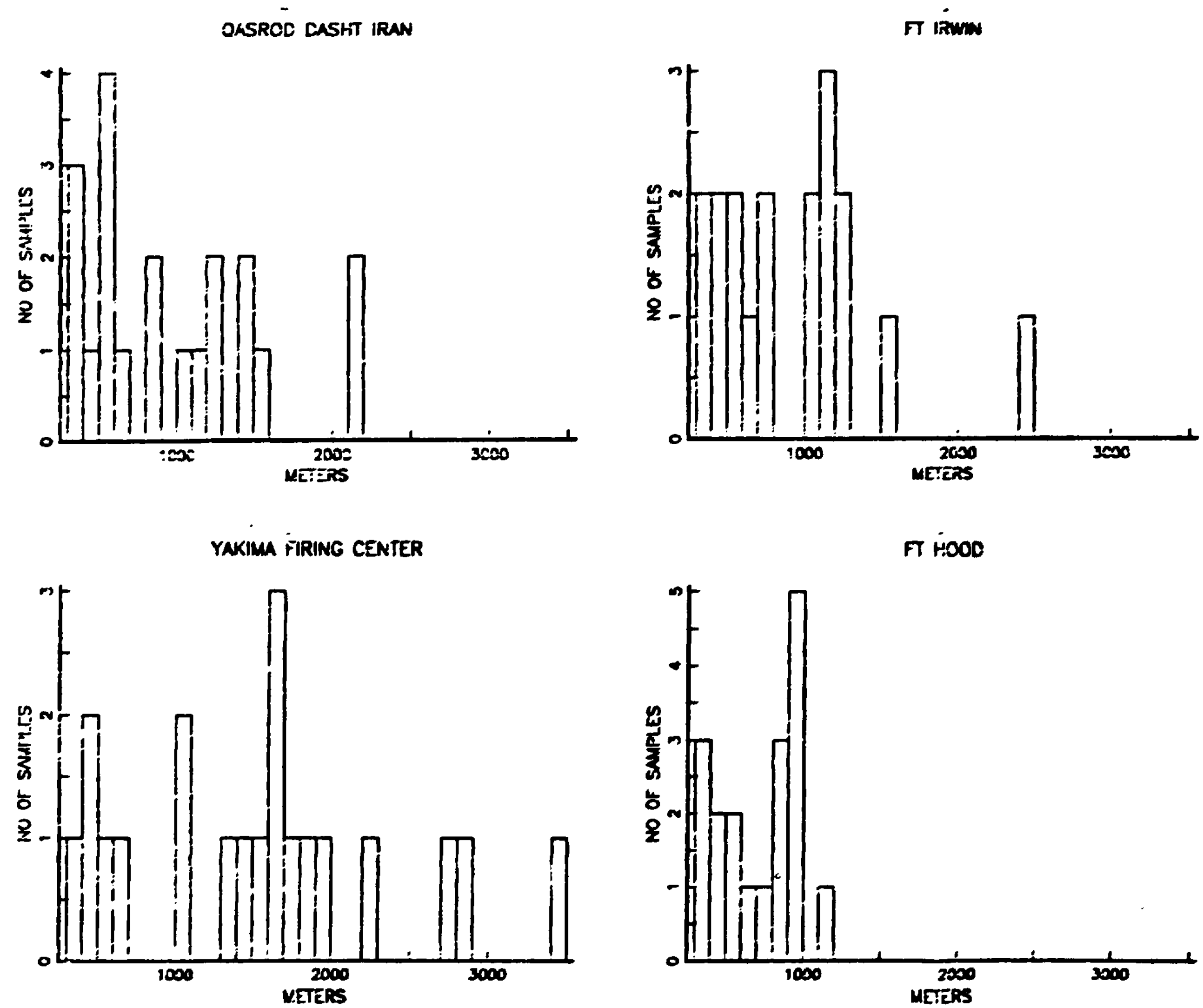


Figure C.4 Comparison of Mean In-View Segments

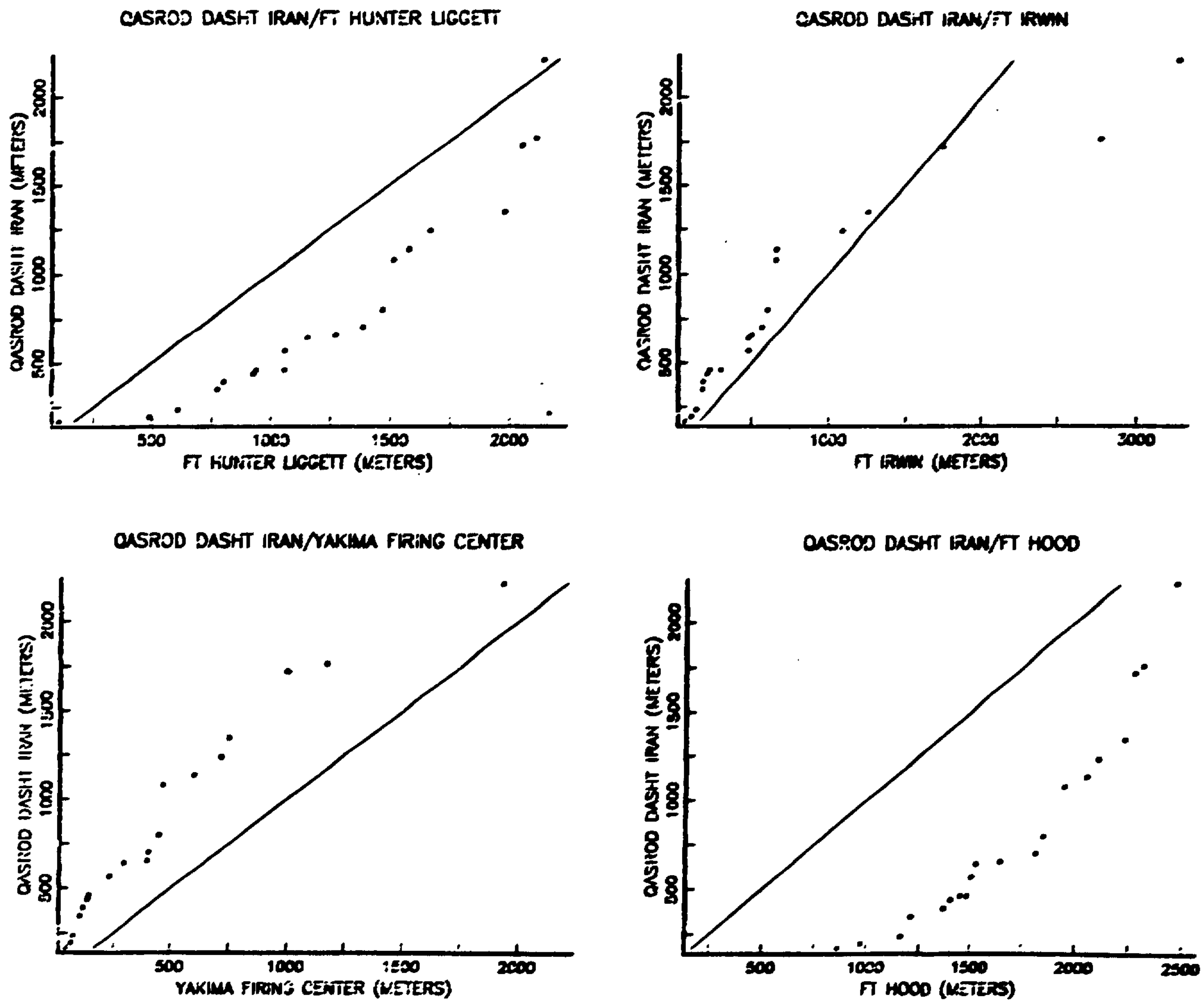


Figure C.5 Empirical Q-Q Plot of Mean Out-of-View Segments

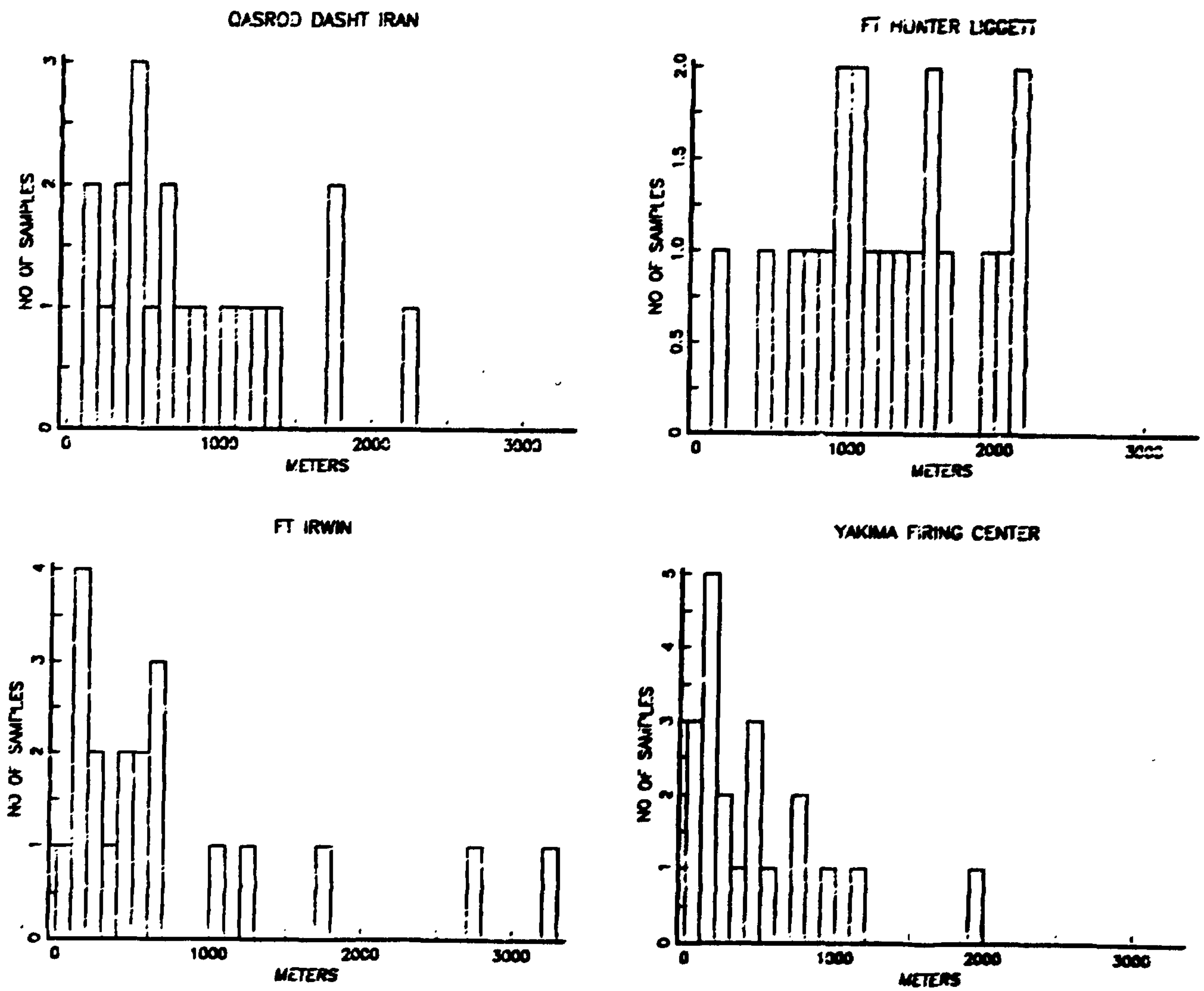


Figure C.6 Comparison of Mean Out-of-View Segments

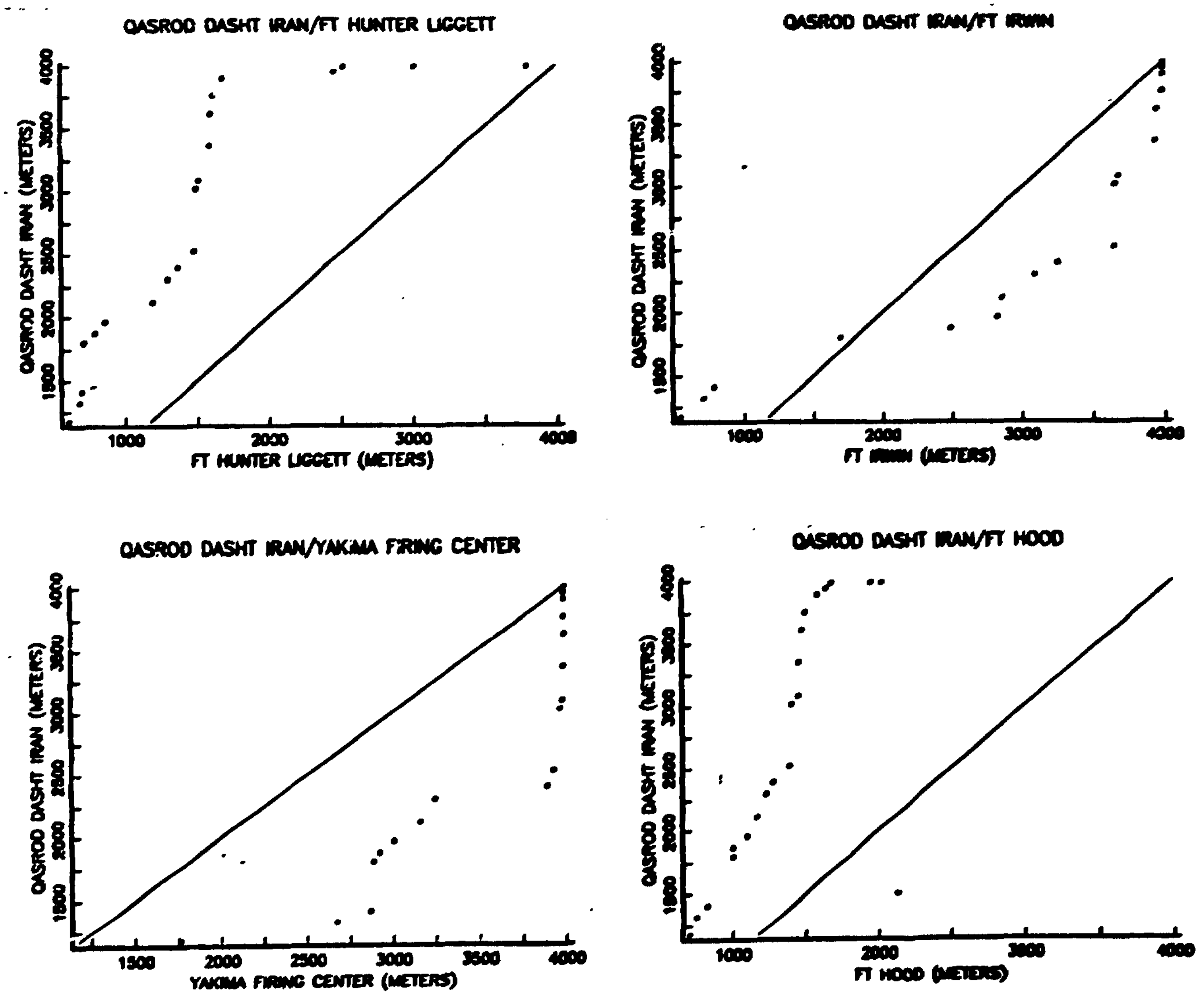


Figure C.7 Empirical Q-Q Plot of Mean First Opening Range

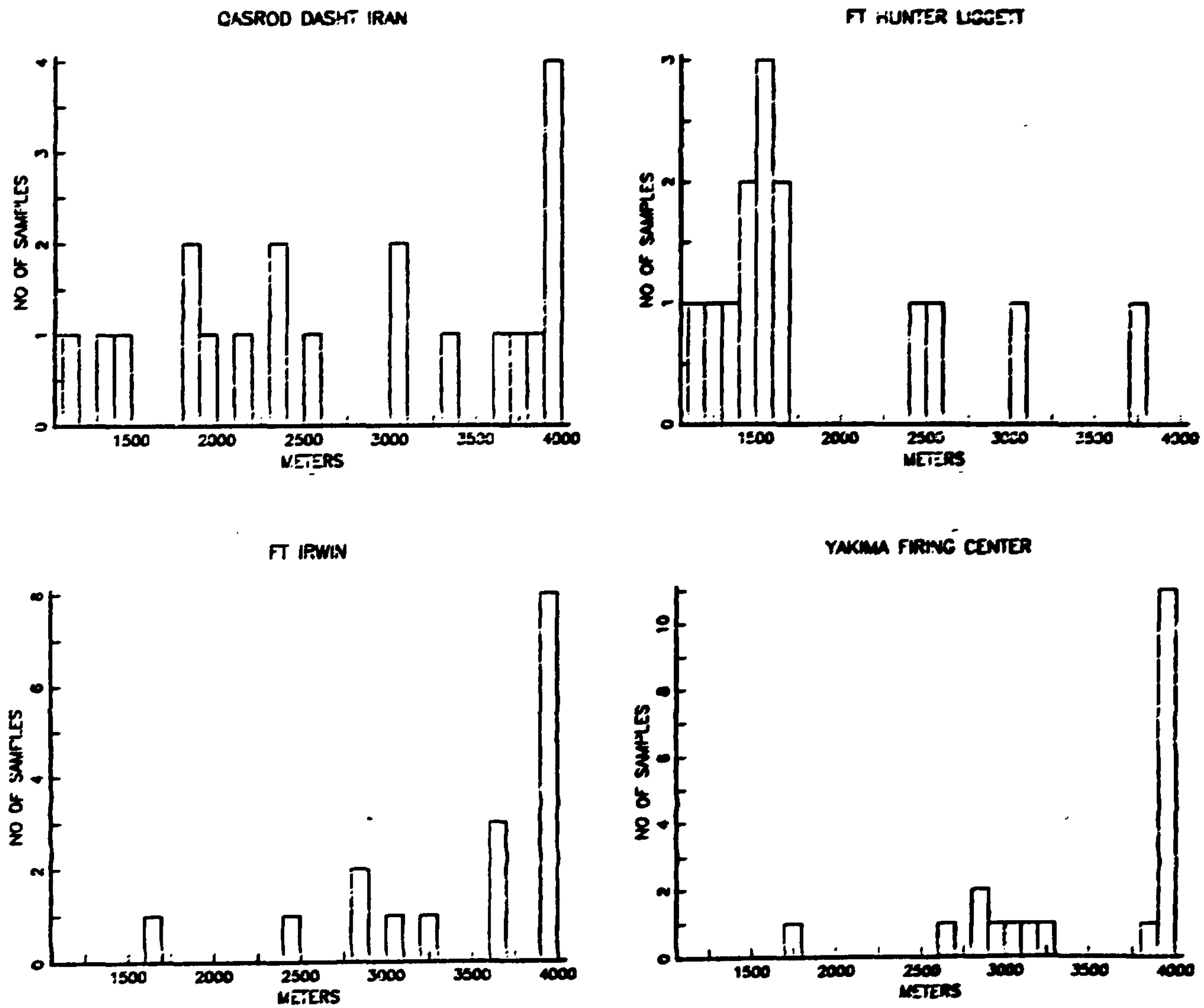


Figure C.8 Comparison of Mean First Opening Range

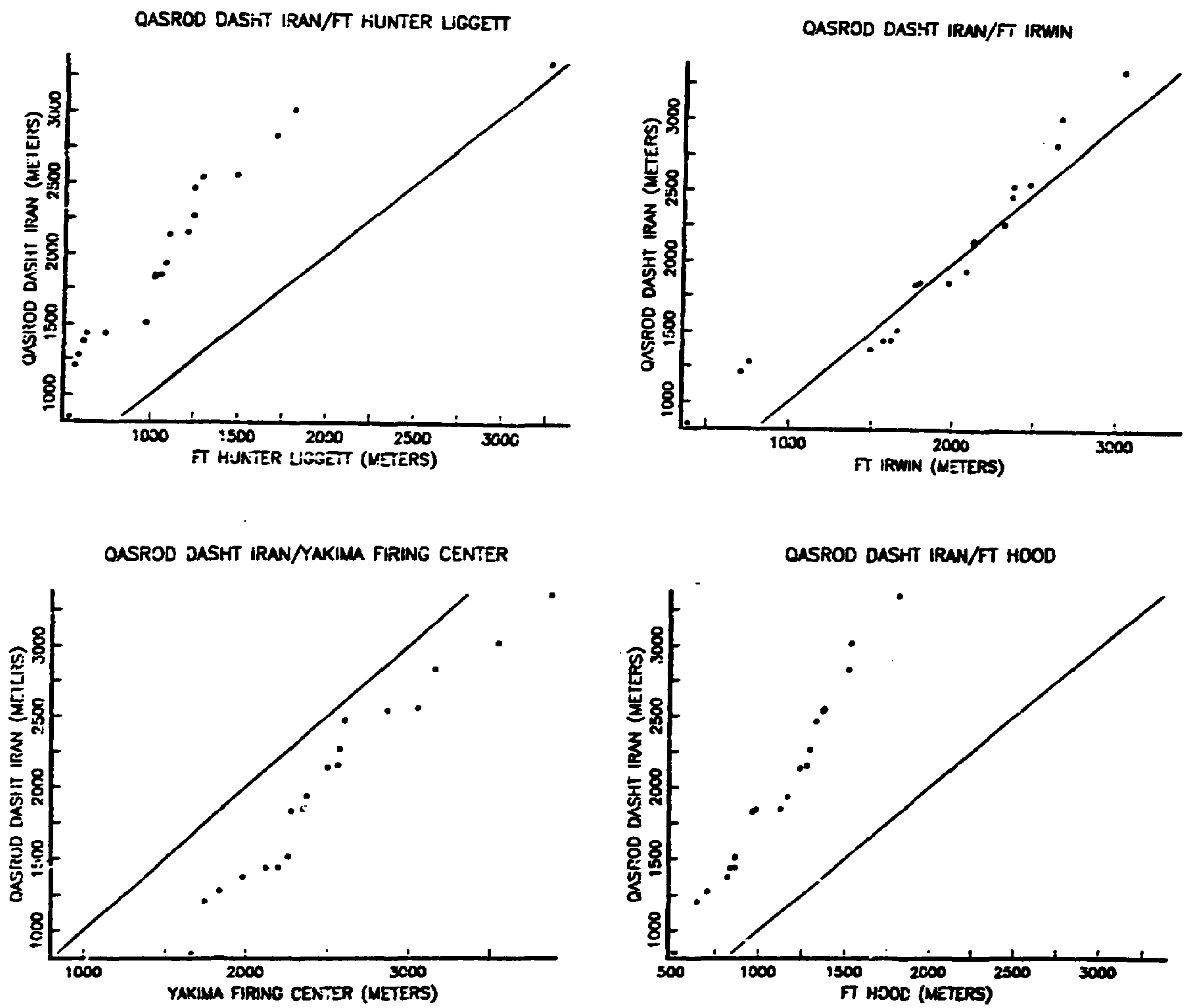


Figure C.9 Empirical Q-Q Plot of Mean Expected Opening Range

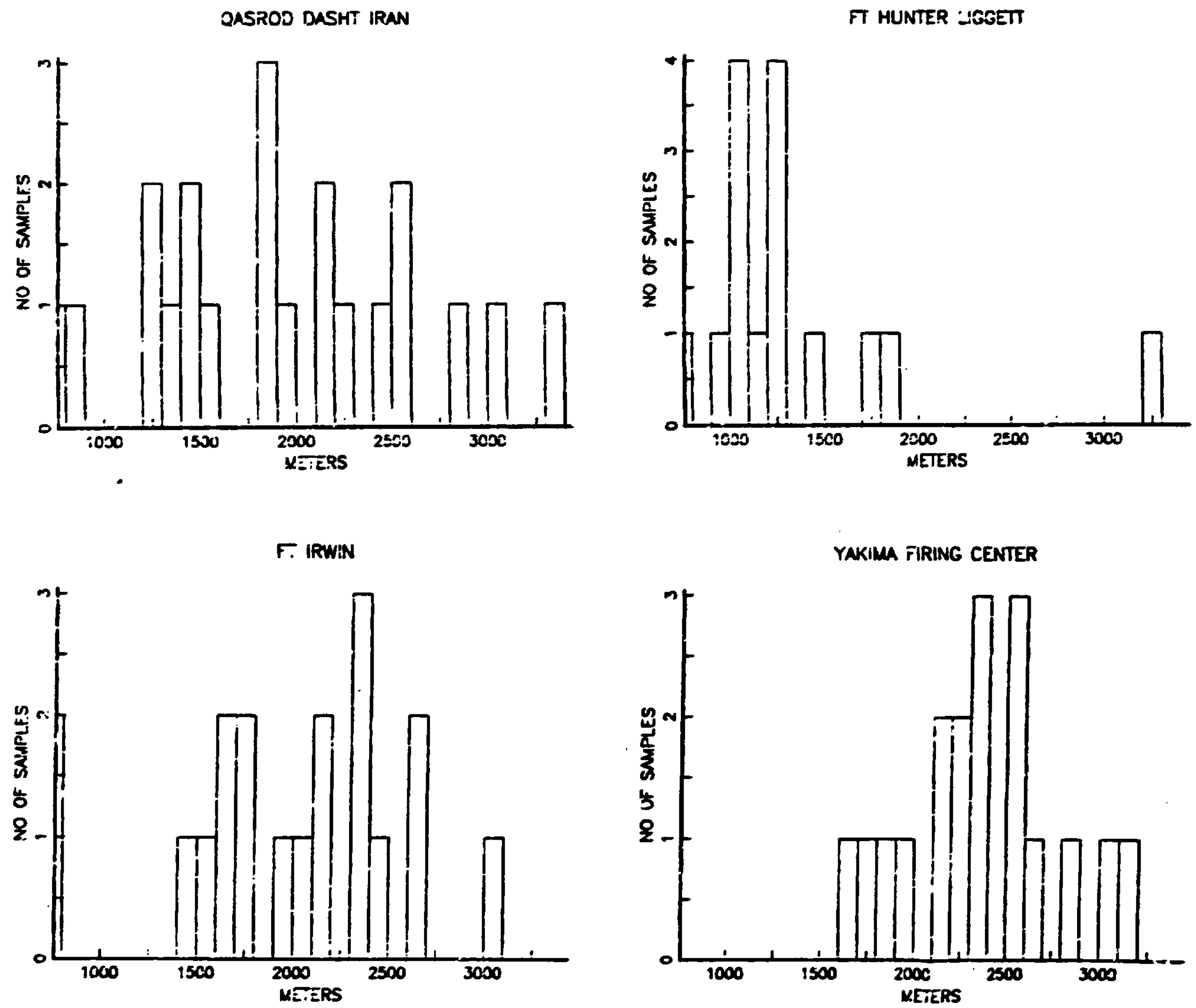


Figure C.10 Comparison of Mean Expected Opening Range

APPENDIX D

COMPARISON OF SOUTH KOREA AND CONUS TEST SITES

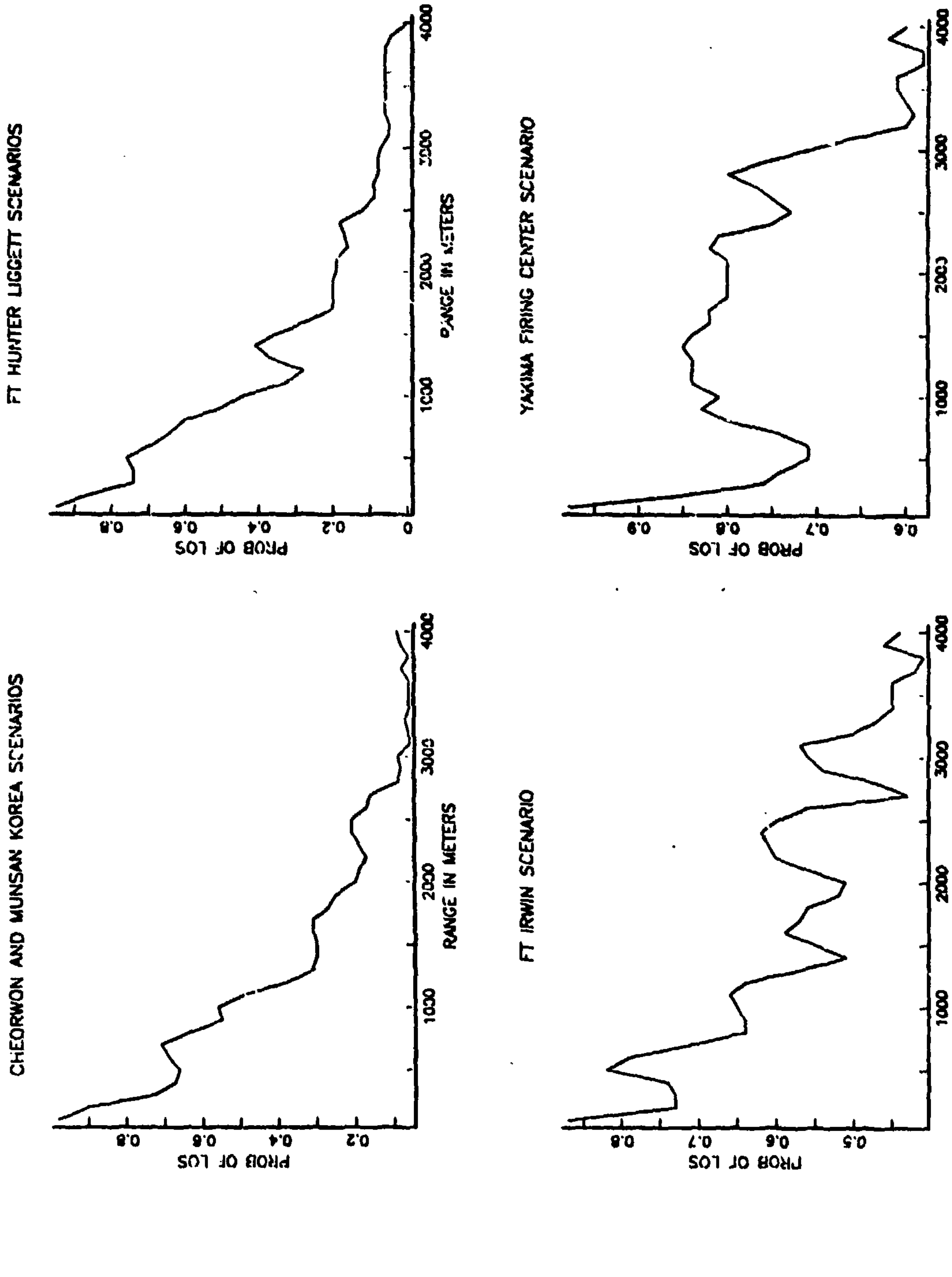


Figure D.1 Probability of Line of Sight Distributions

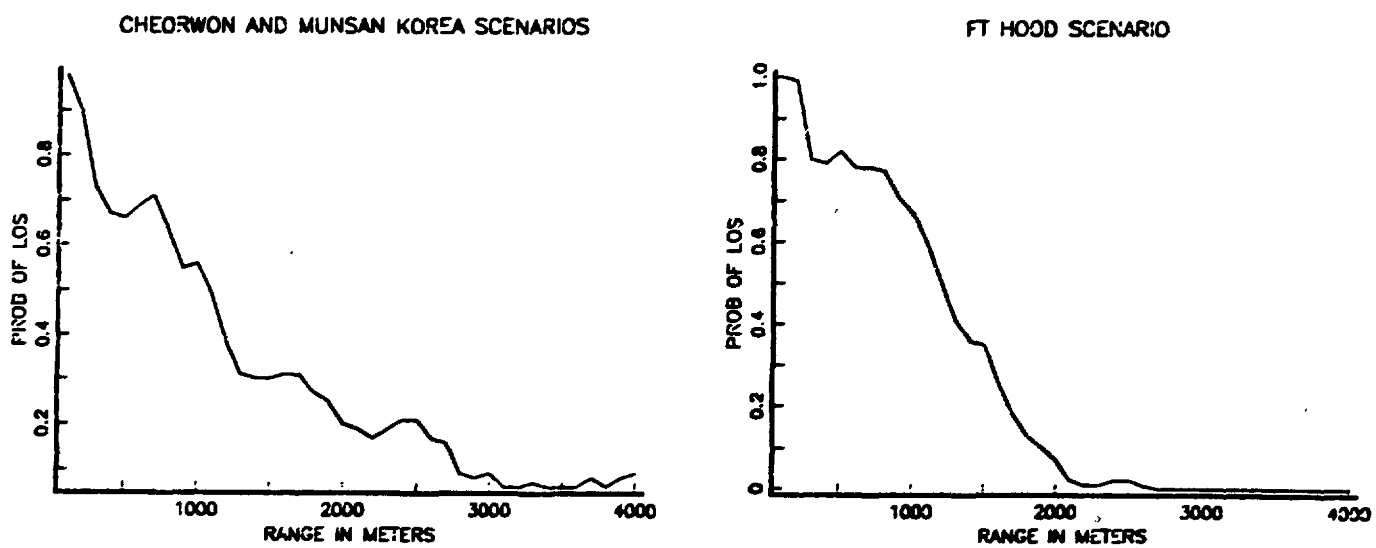


Figure D.2 Probability of Line of Sight Distributions

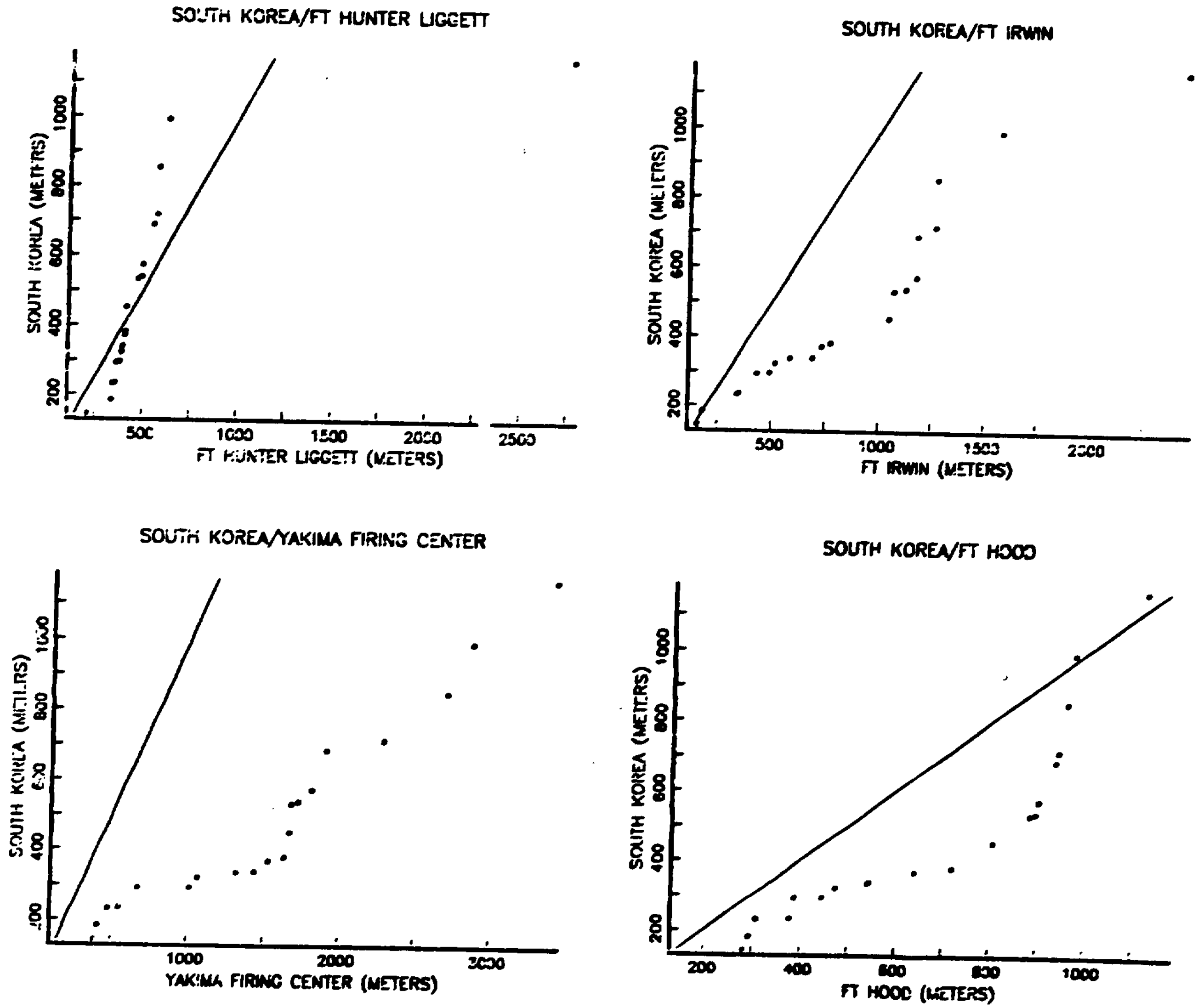


Figure D.3 Empirical Q-Q Plot of Mean in-View Segments

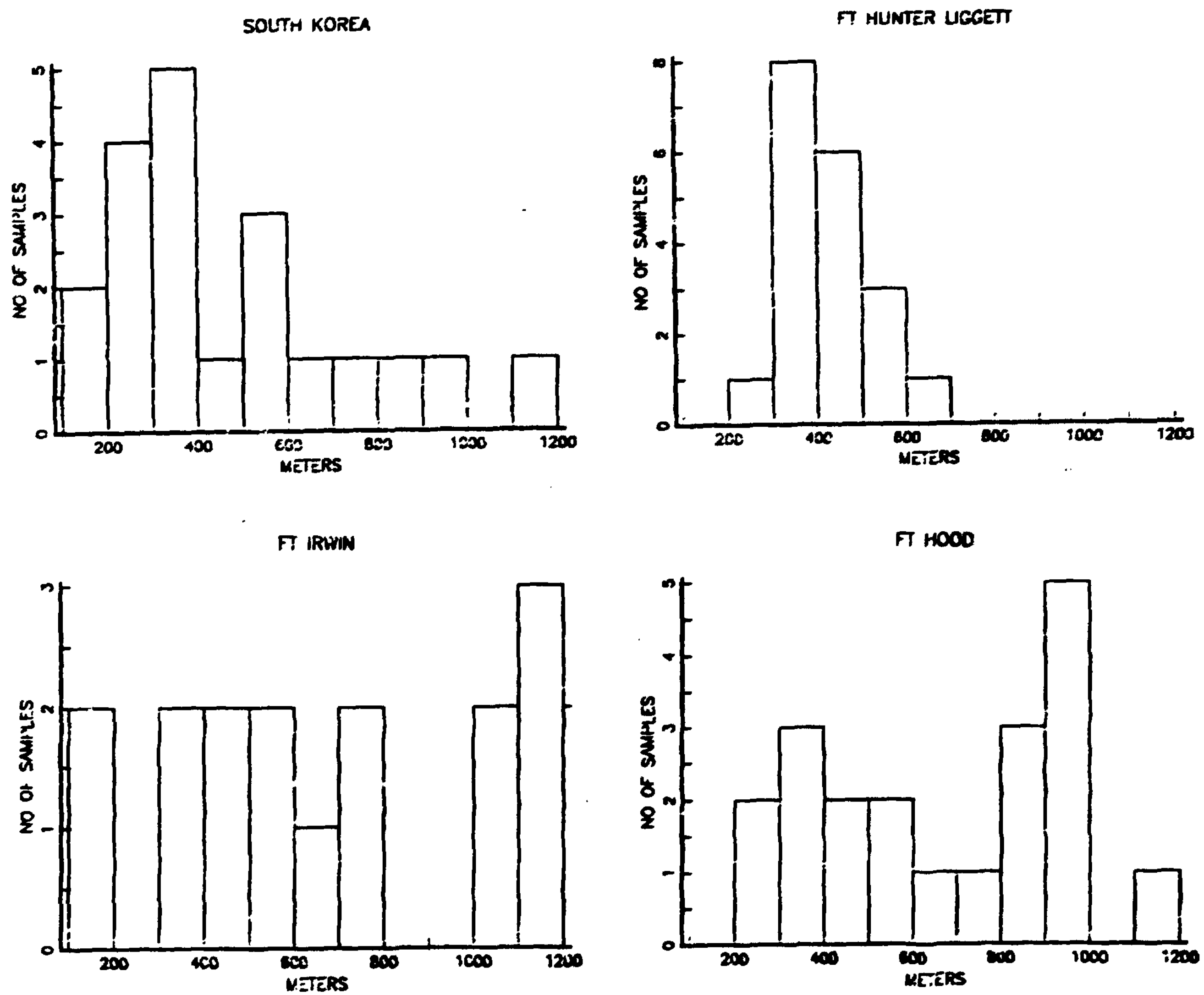


Figure D.4 Comparison of Mean In-View Segments

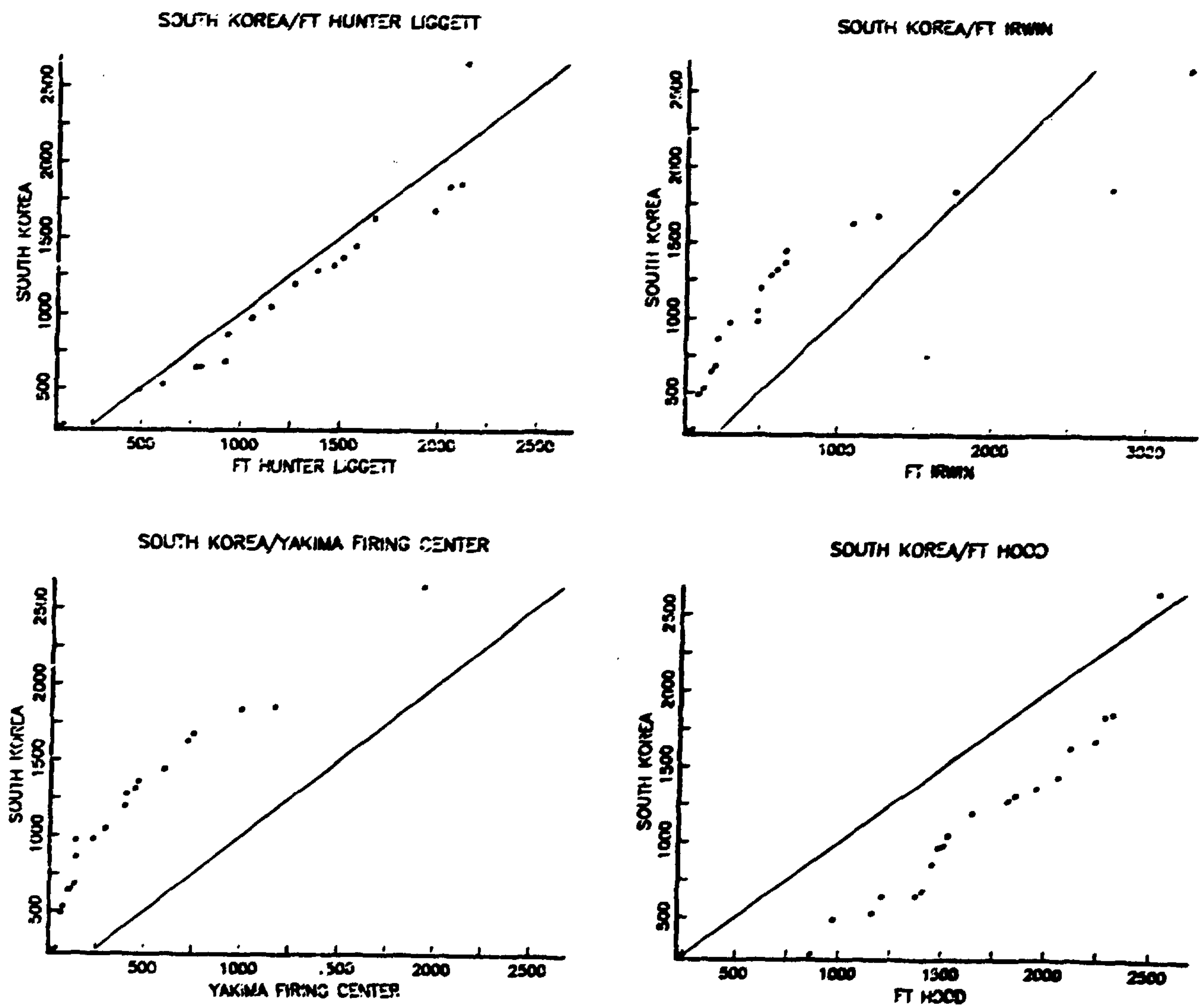


Figure D.5 Empirical Q-Q Plot of Mean Out-of-View Segments

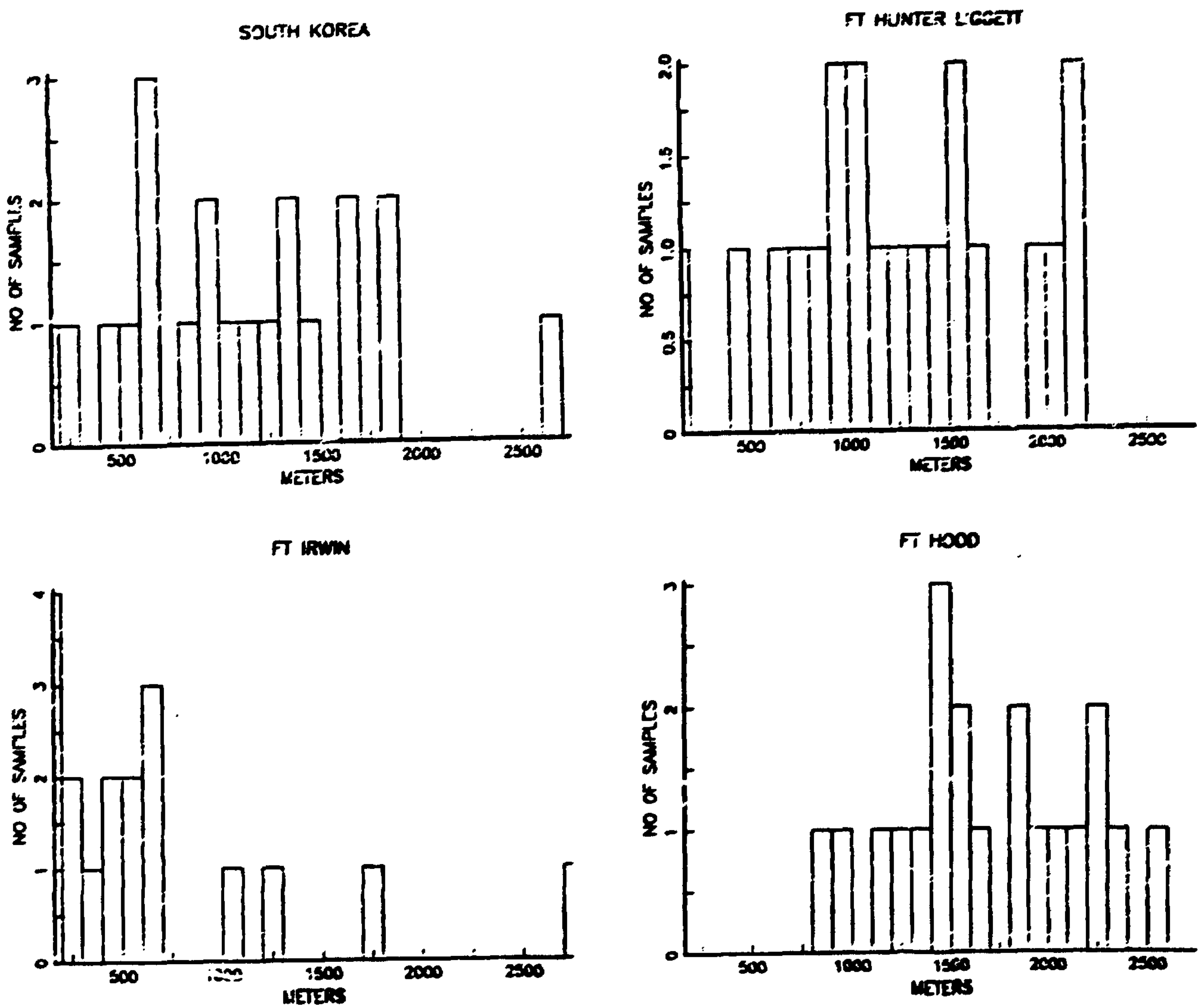


Figure D.6 Comparison of Mean Out-Of-View Segments

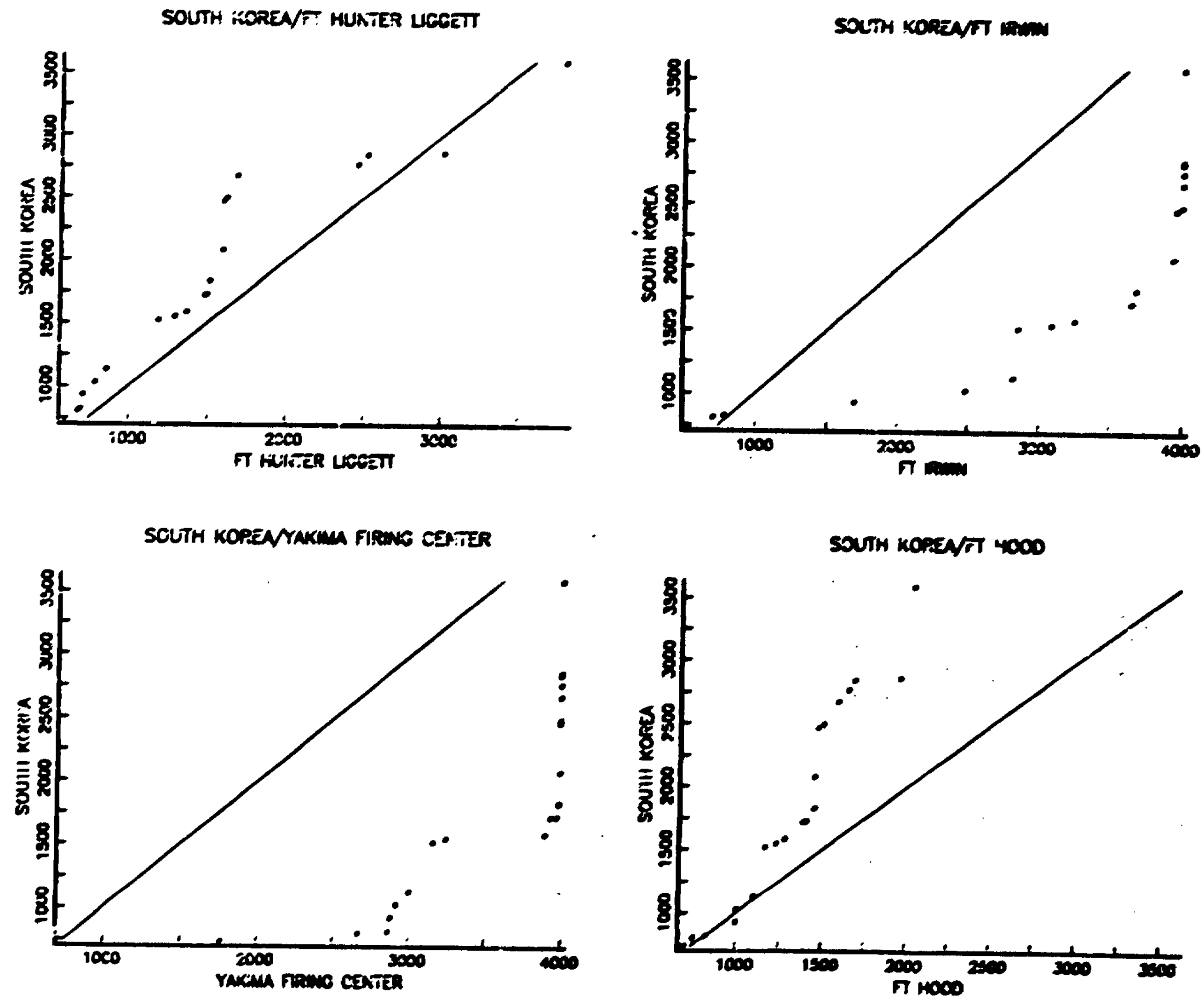


Figure D.7 Empirical Q-Q Plot of Mean First Opening Range

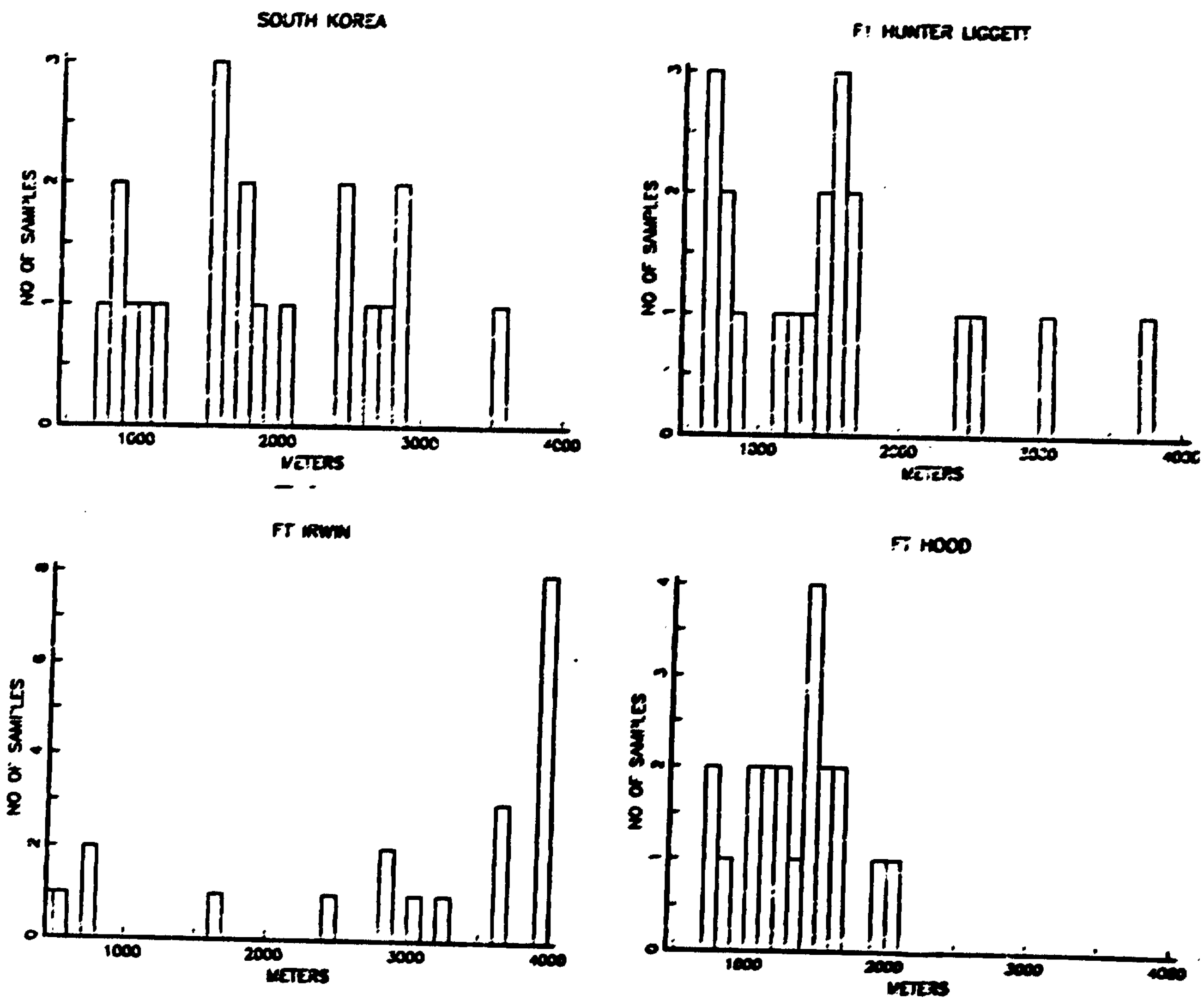


Figure D.8 Comparison of Mean First Opening Range

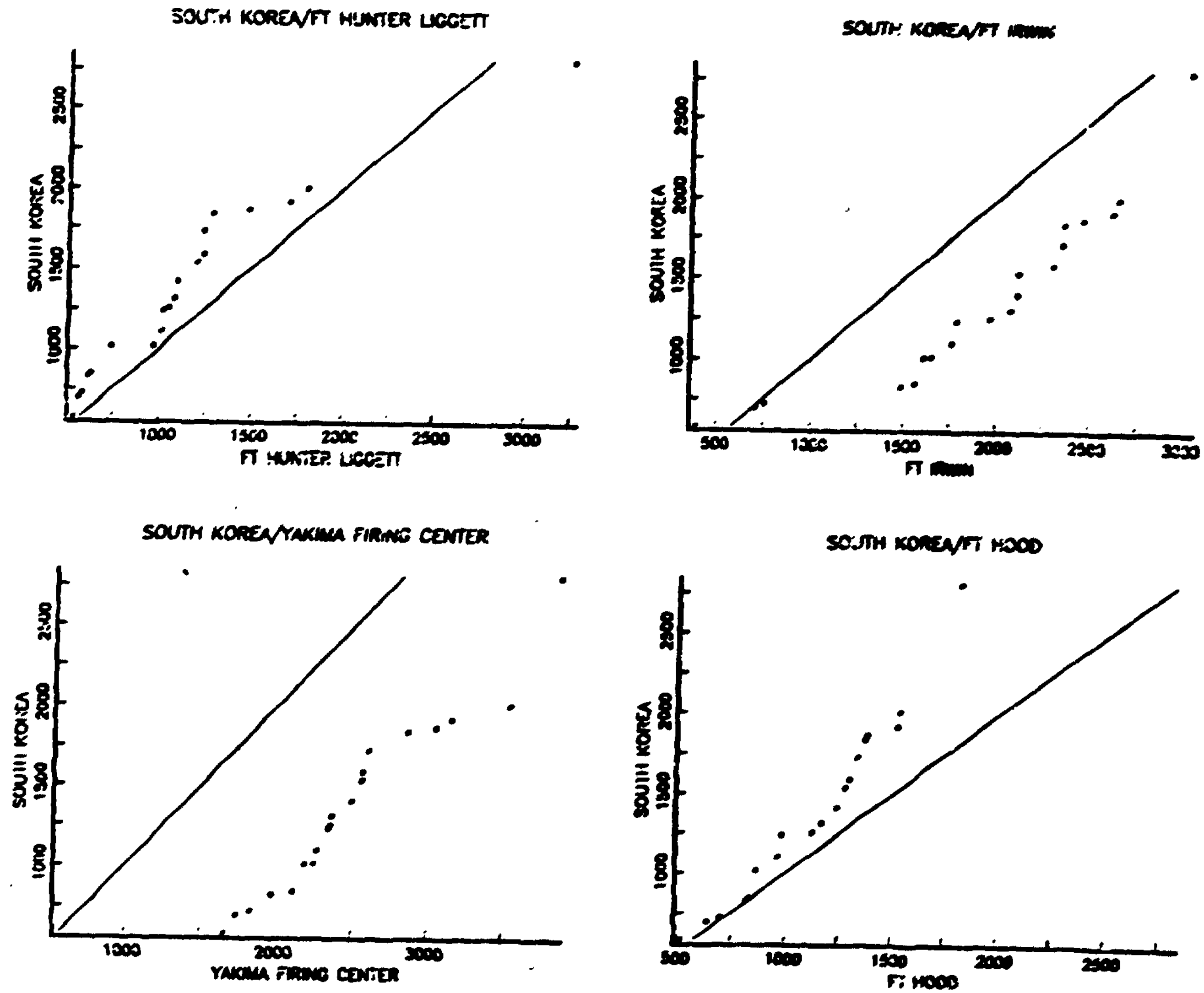


Figure D.9 Empirical Q-Q Plot of Mean Expected Opening Range

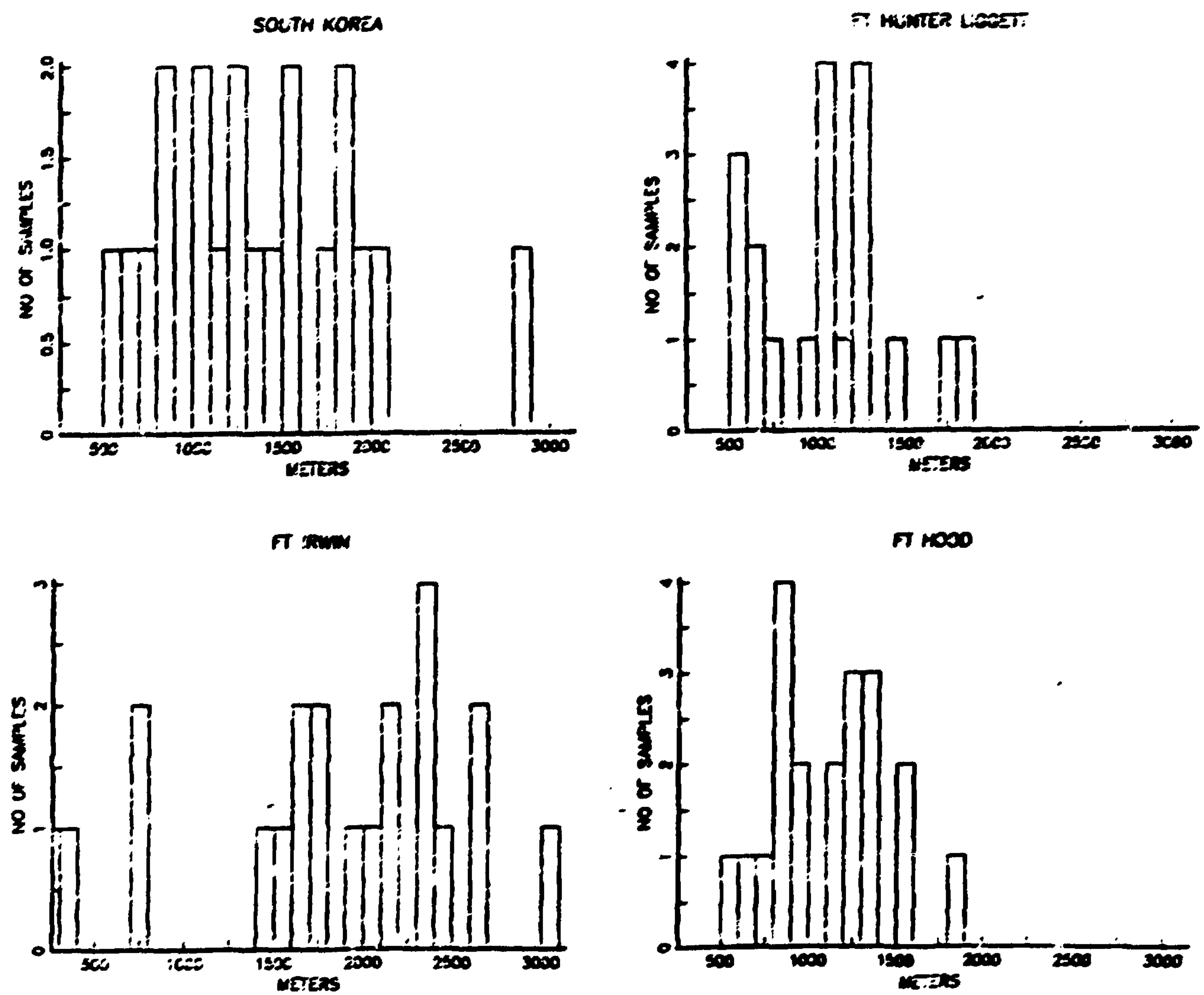


Figure D.10 Comparison of Mean Expected Opening Range

APPENDIX E

FITTED PLOTS OF FULDA GAP, QASROD DASHT, IRAN, SOUTH KOREA AND CONUS TEST SITES

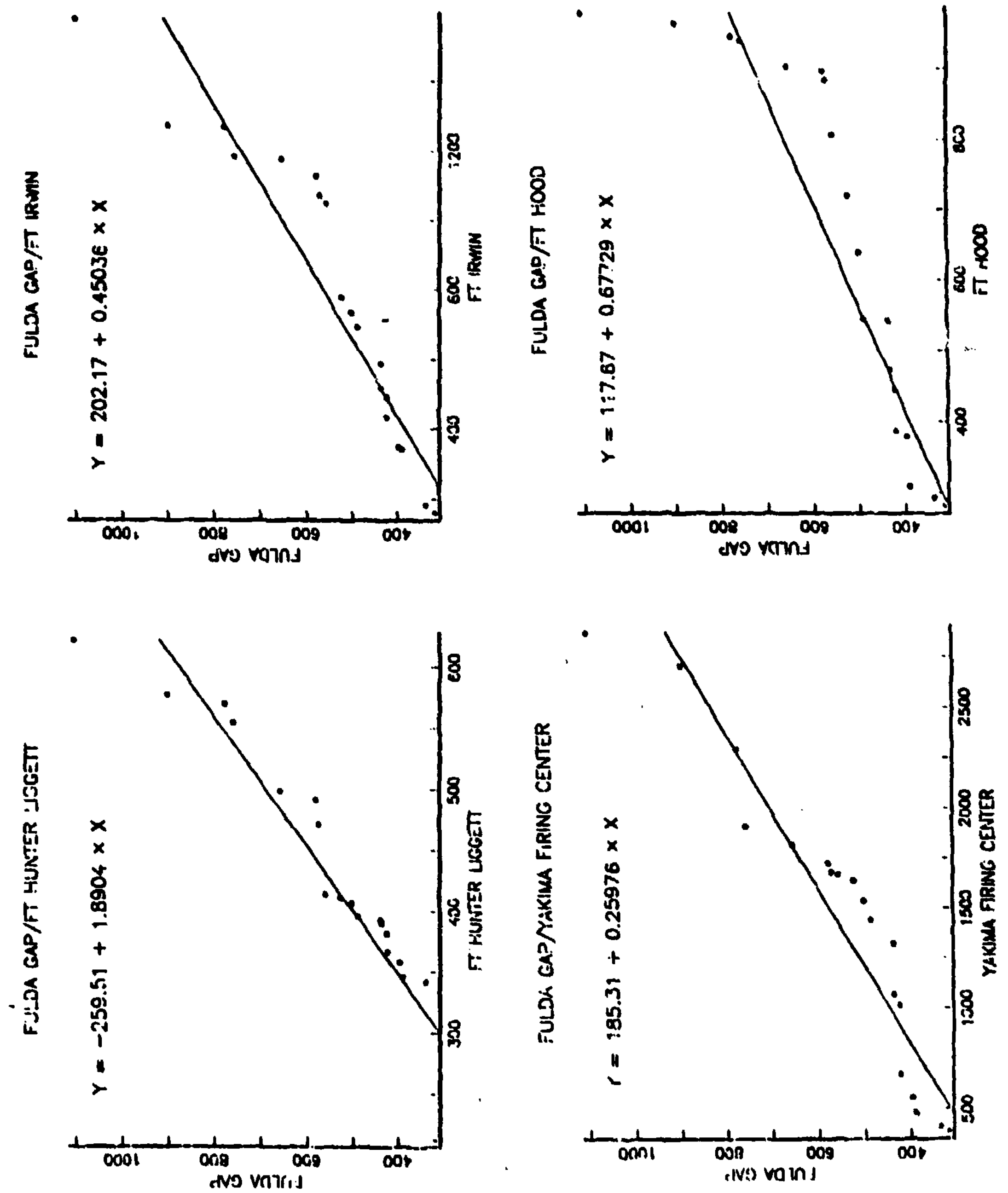


Figure E.1 Fitted Q-Q Plots of Mean In-View Segments

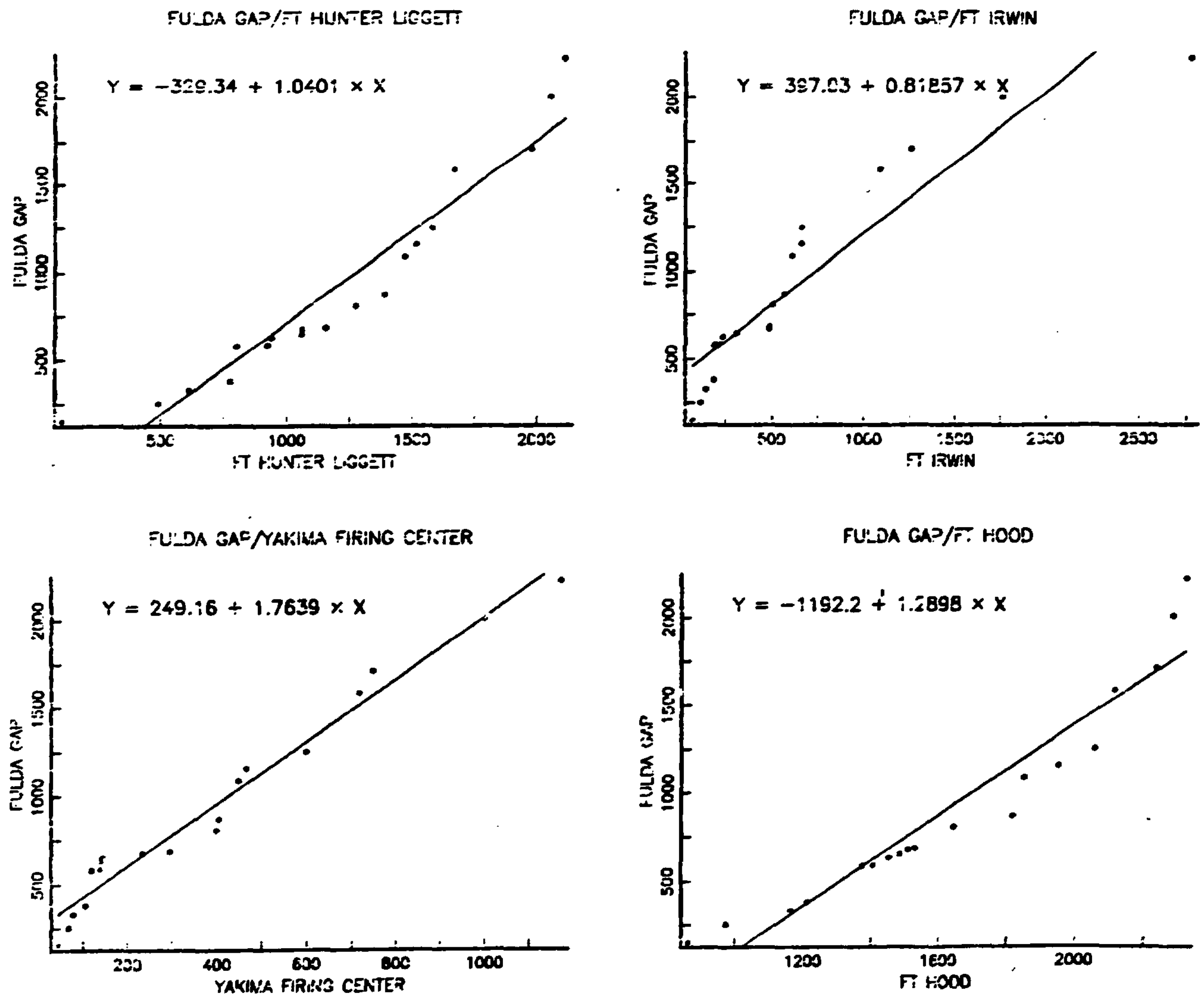


Figure E.2 Fitted Q-Q Plots of Mean Out-Of-View Segments

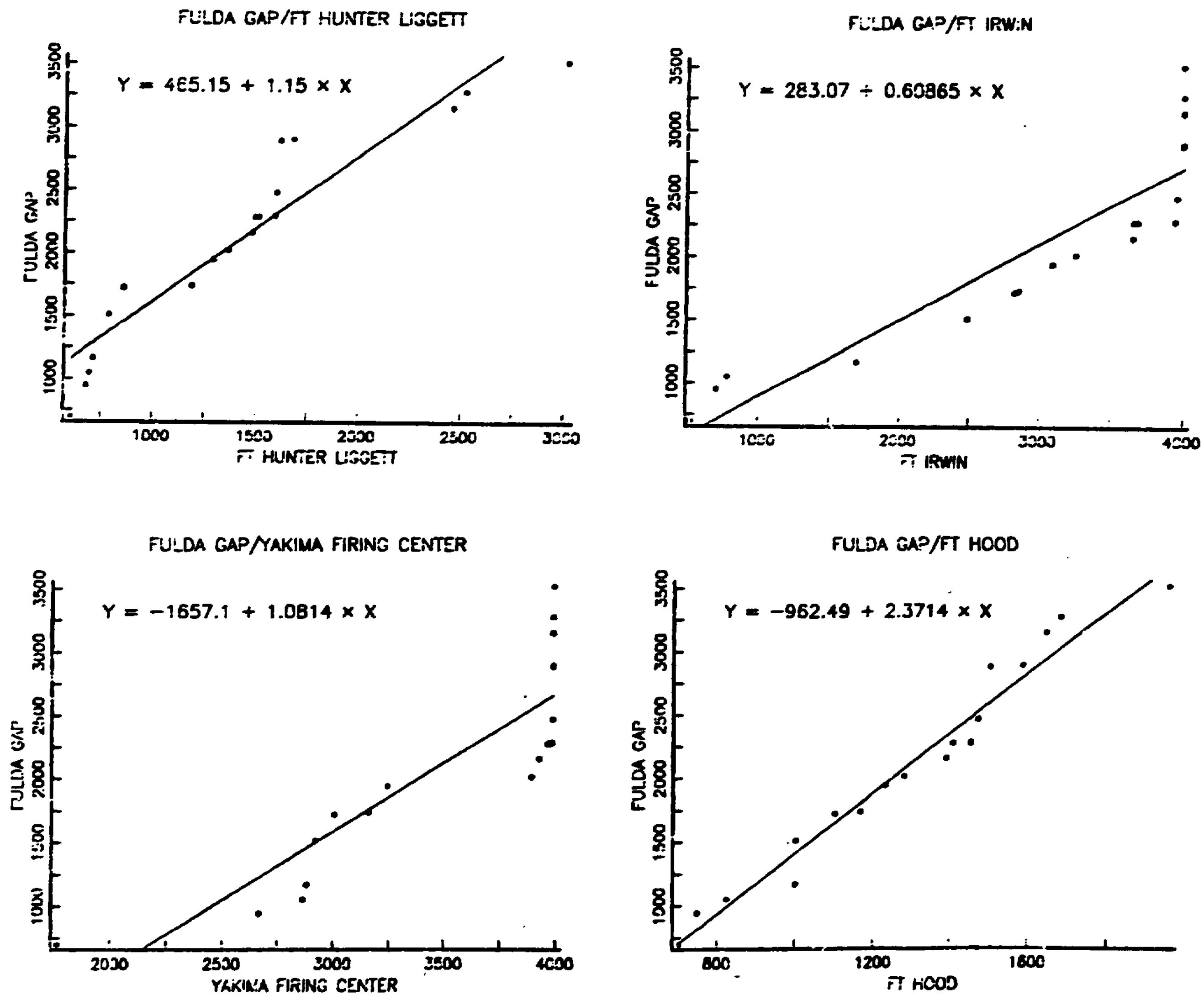


Figure E.3 Fitted Q-Q Plots of Mean First Opening Range

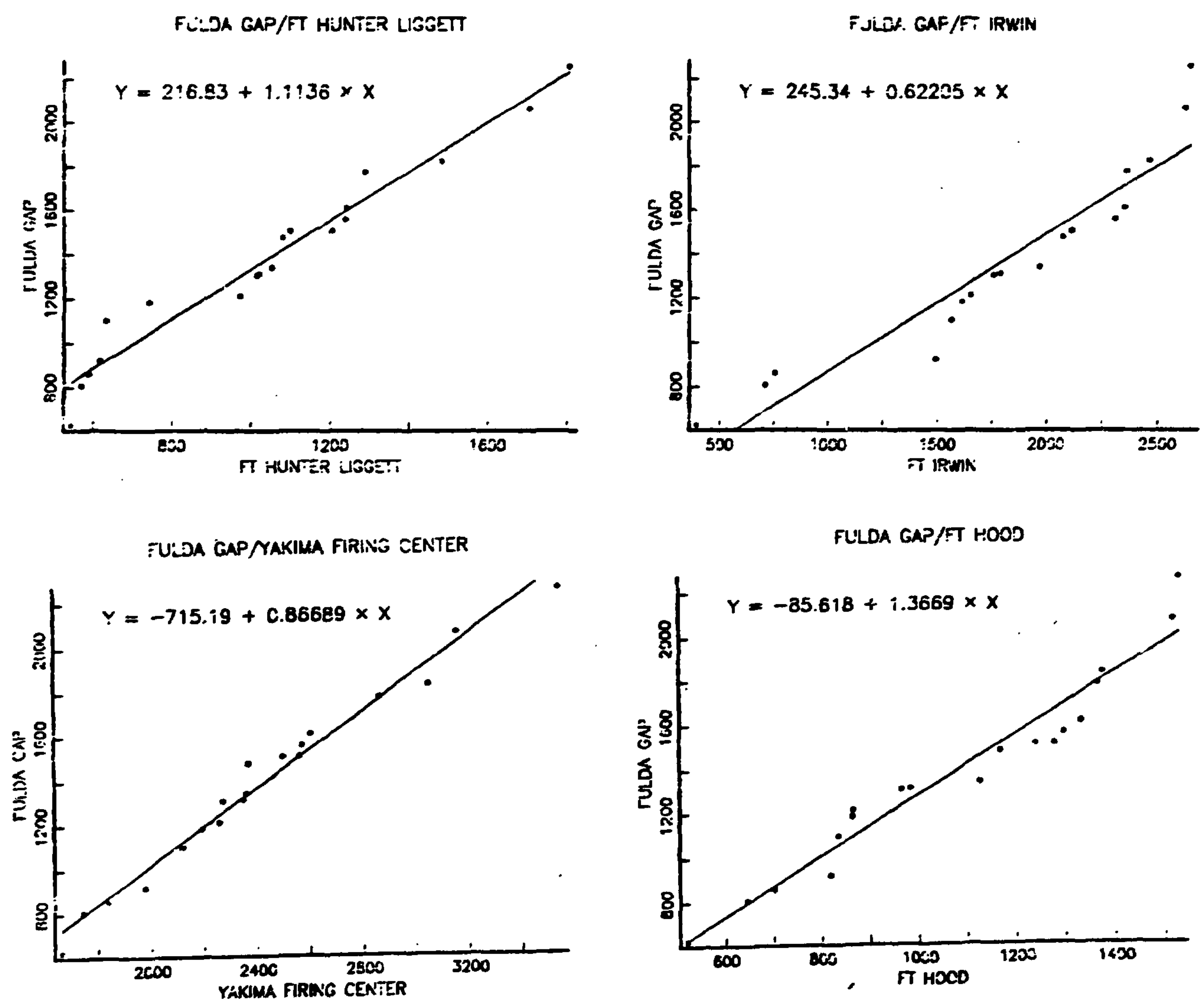


Figure E.4 Fitted Q-Q Plots of Mean Expected Opening Range

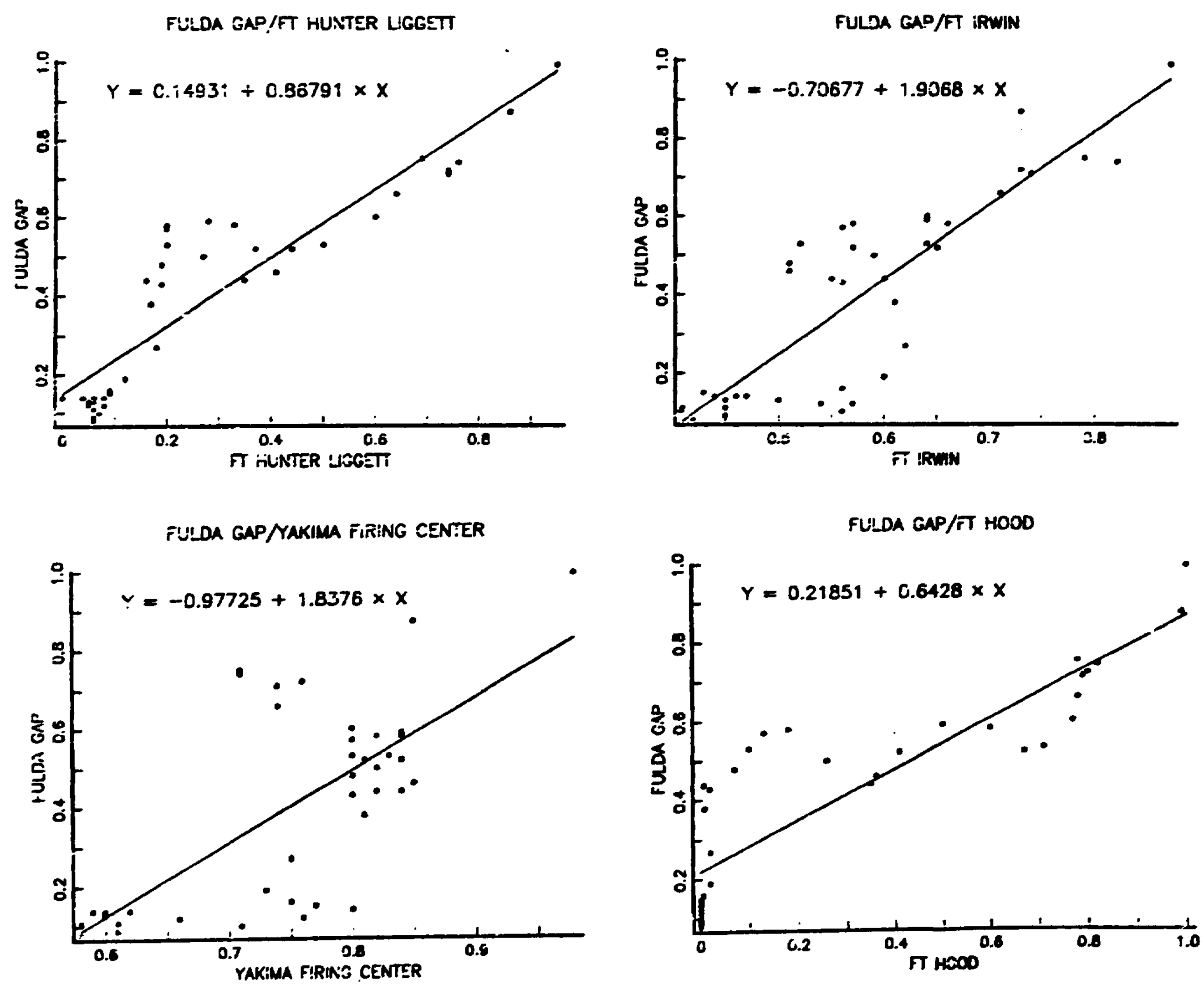


Figure E.5 Fitted Probability of Line of Sight Plots

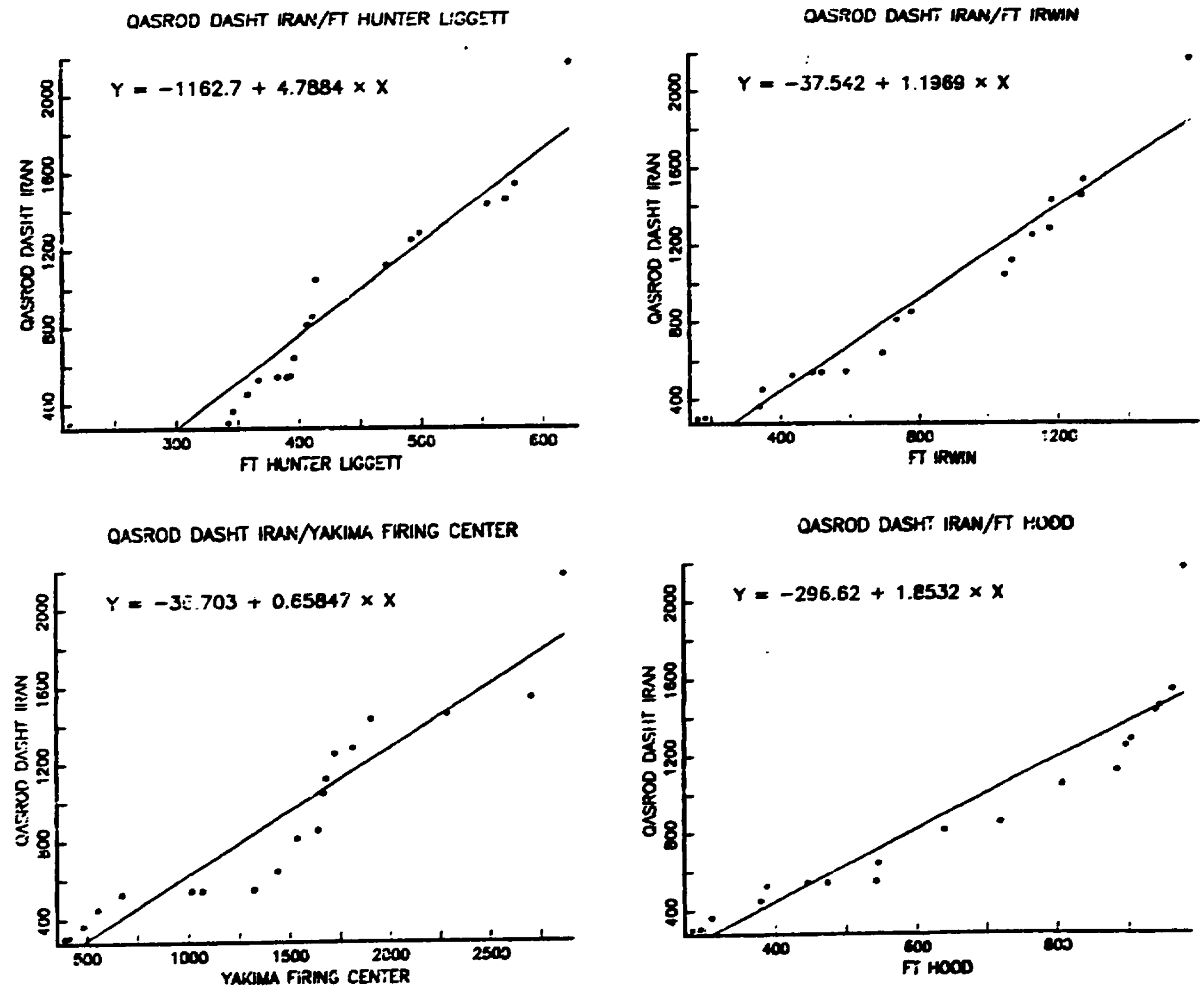


Figure E.6 Fitted Q-Q Plots of Mean In-View Segments

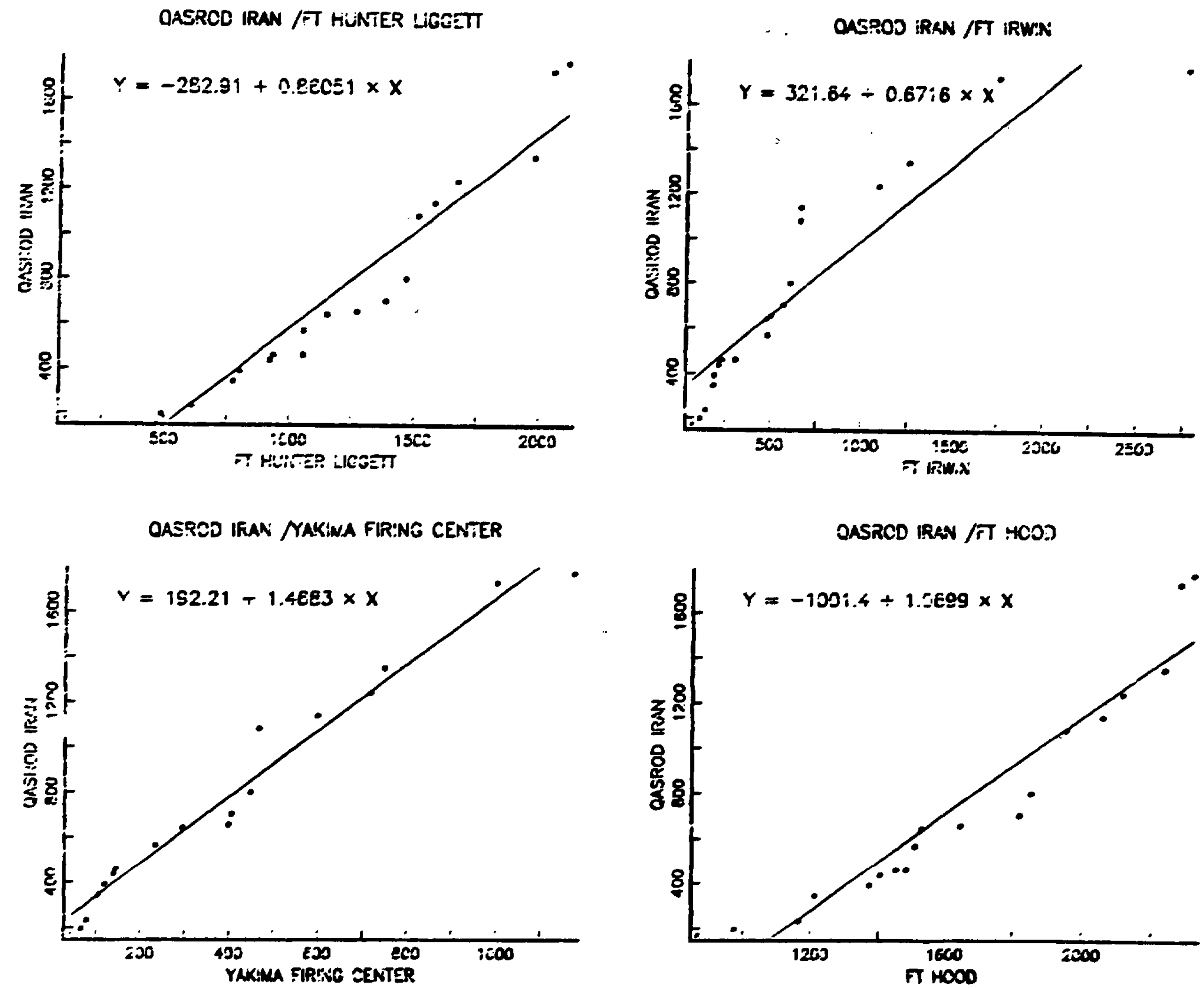


Figure E.7 Fitted Q-Q Plots of Mean Out-of-View Segments

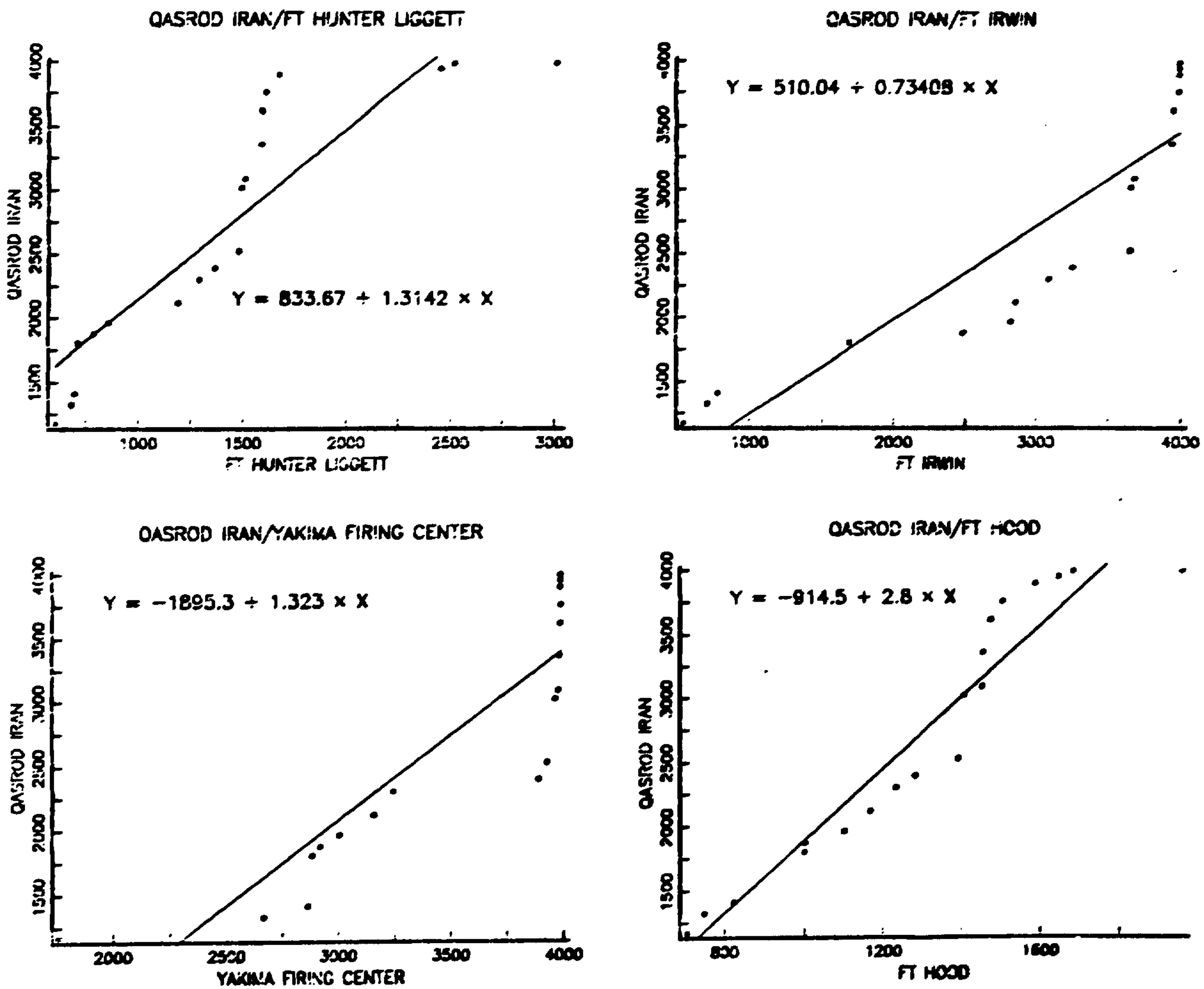


Figure E.8 Fitted Q-Q Plots of Mean First Opening Range

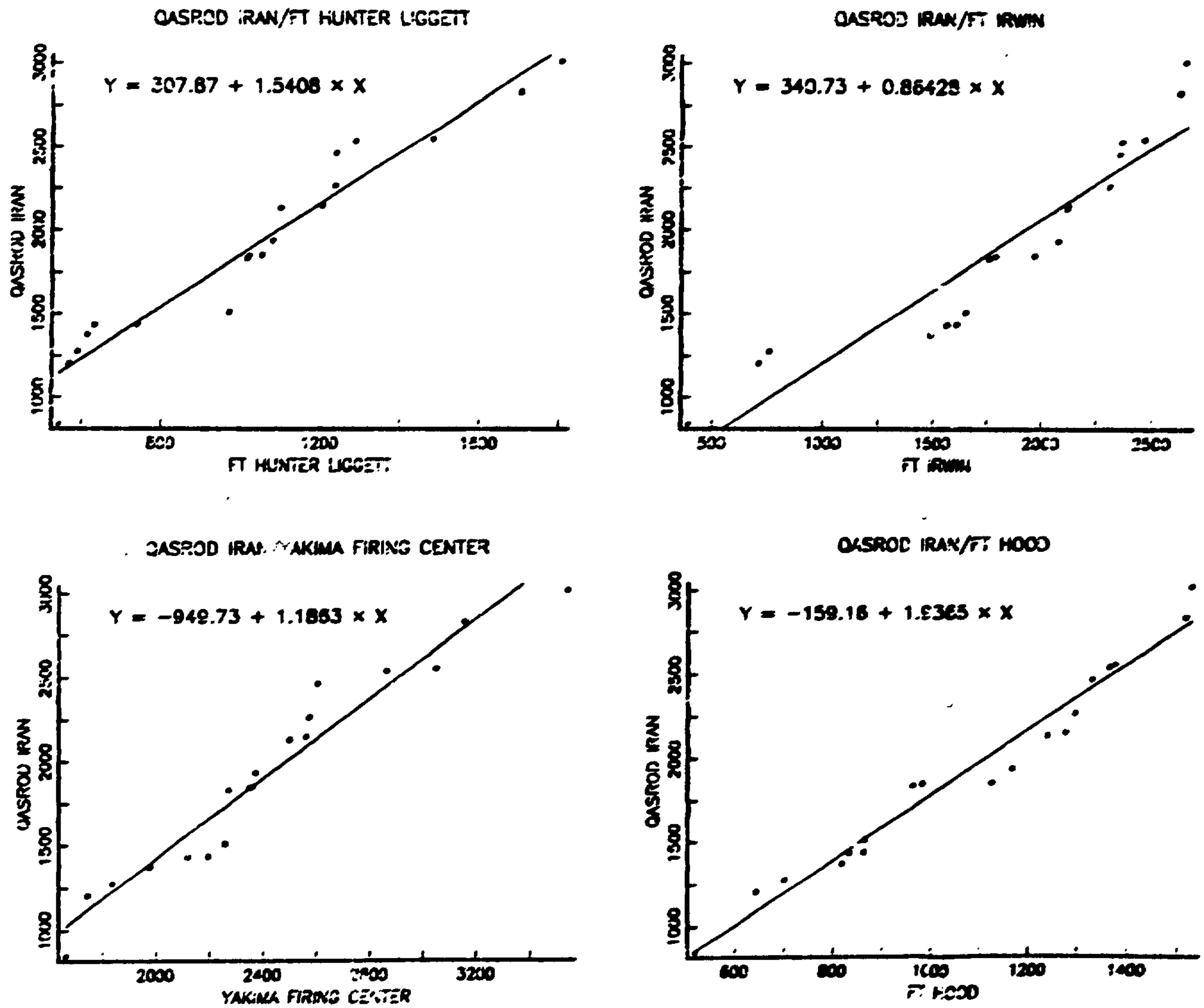


Figure E.9 Fitted Q-Q Plots of Mean Expected Opening Range

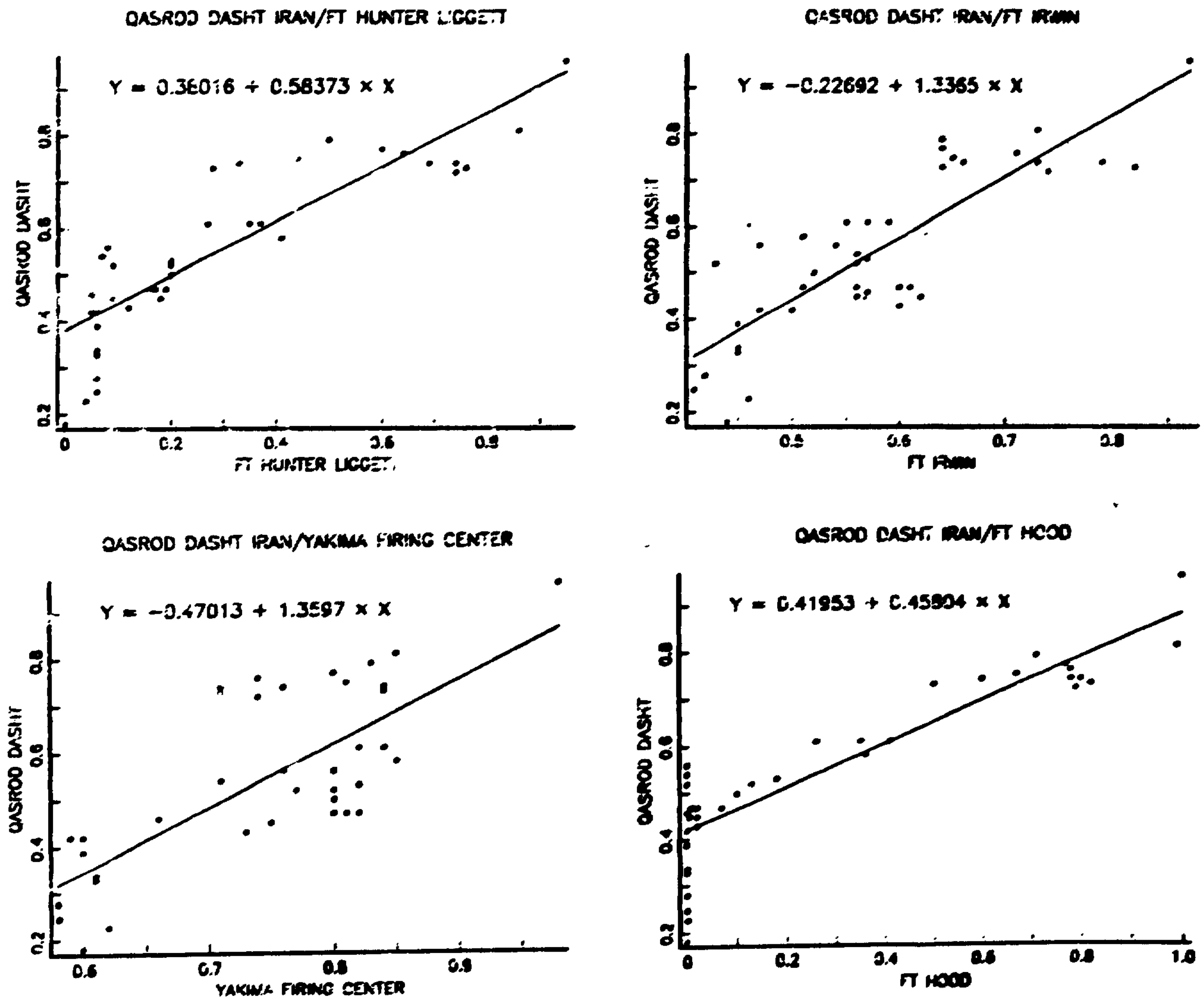


Figure E.10 Fitted Probability of Line of Sight Plots

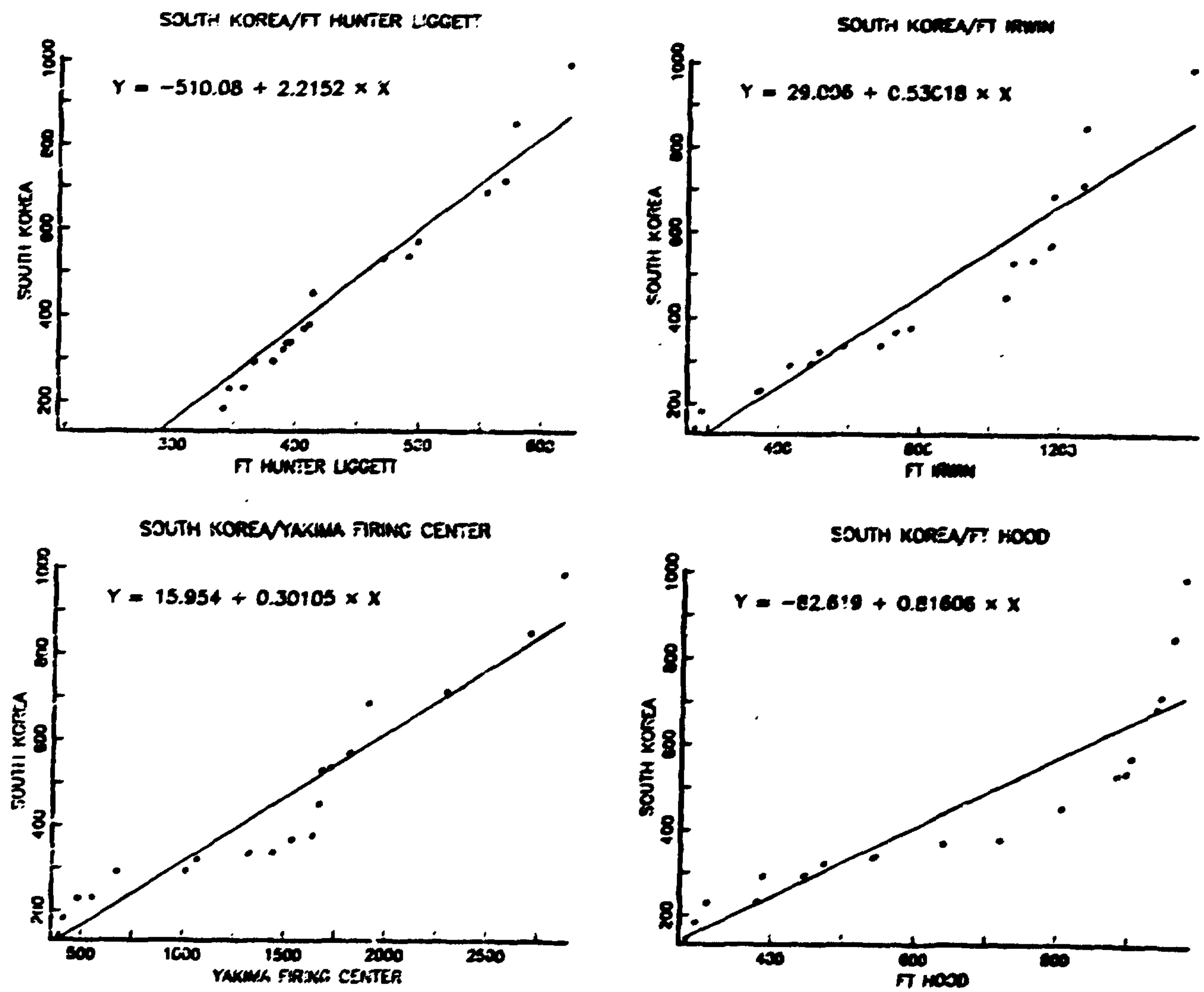


Figure E.11 Fitted Q-Q Plots of Mean In-View Segments

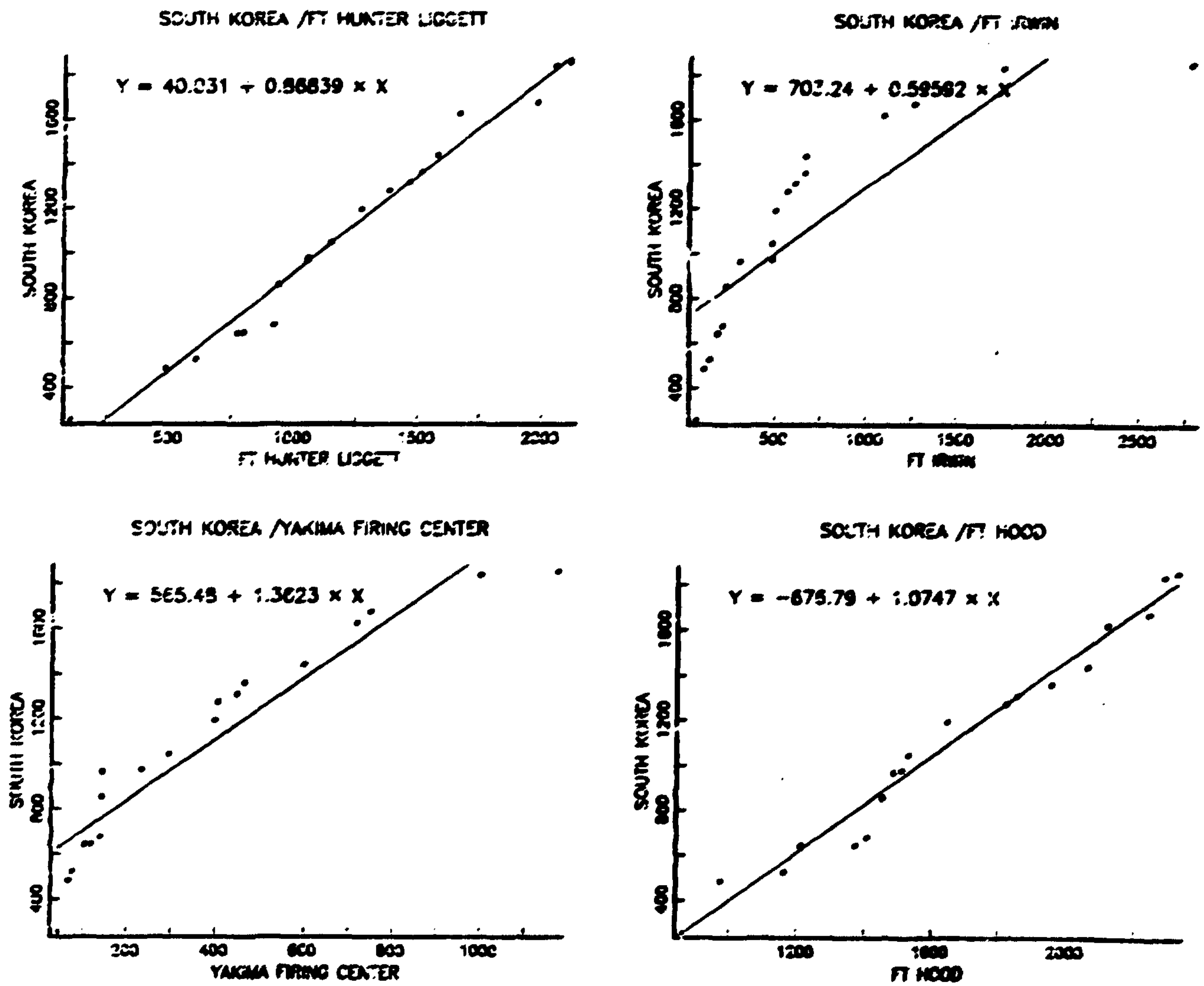


Figure E.12 Fitted Q-Q Plots of Mean Out-of-View Segments

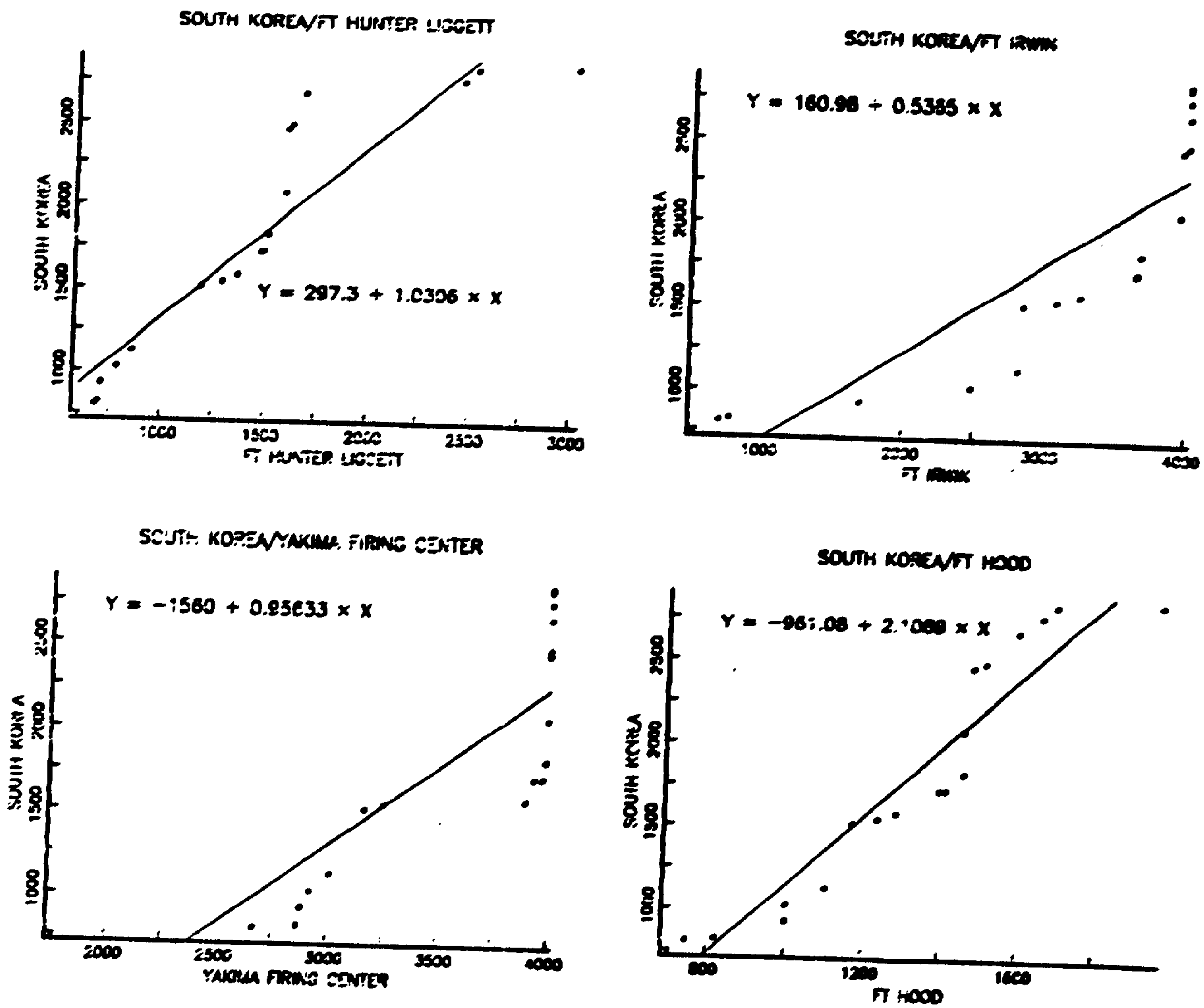


Figure E.13 Fitted Q-Q Plots of Mean First Opening Range

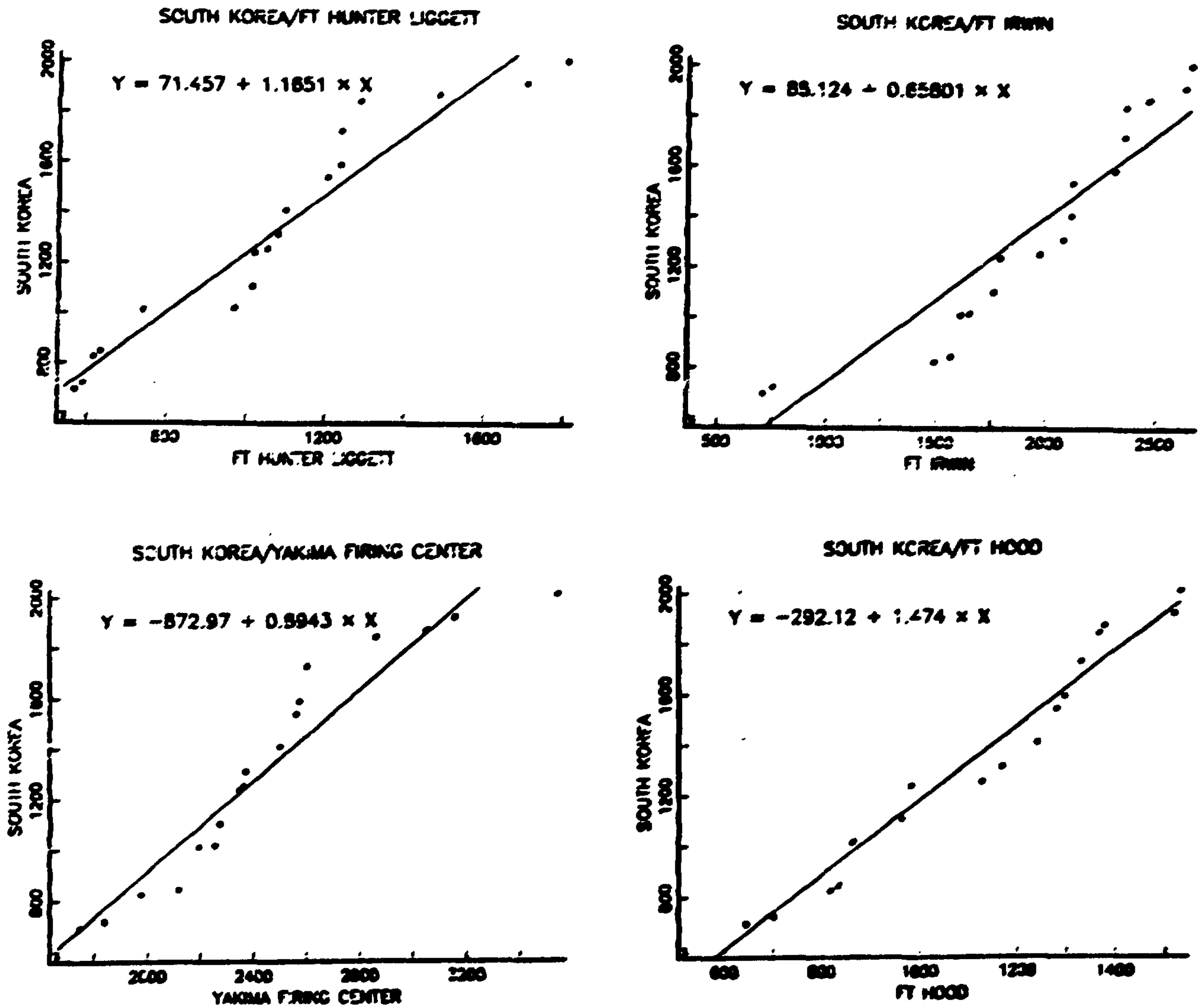


Figure E.14 Fitted Q-Q Plots of Mean Expected Opening Range

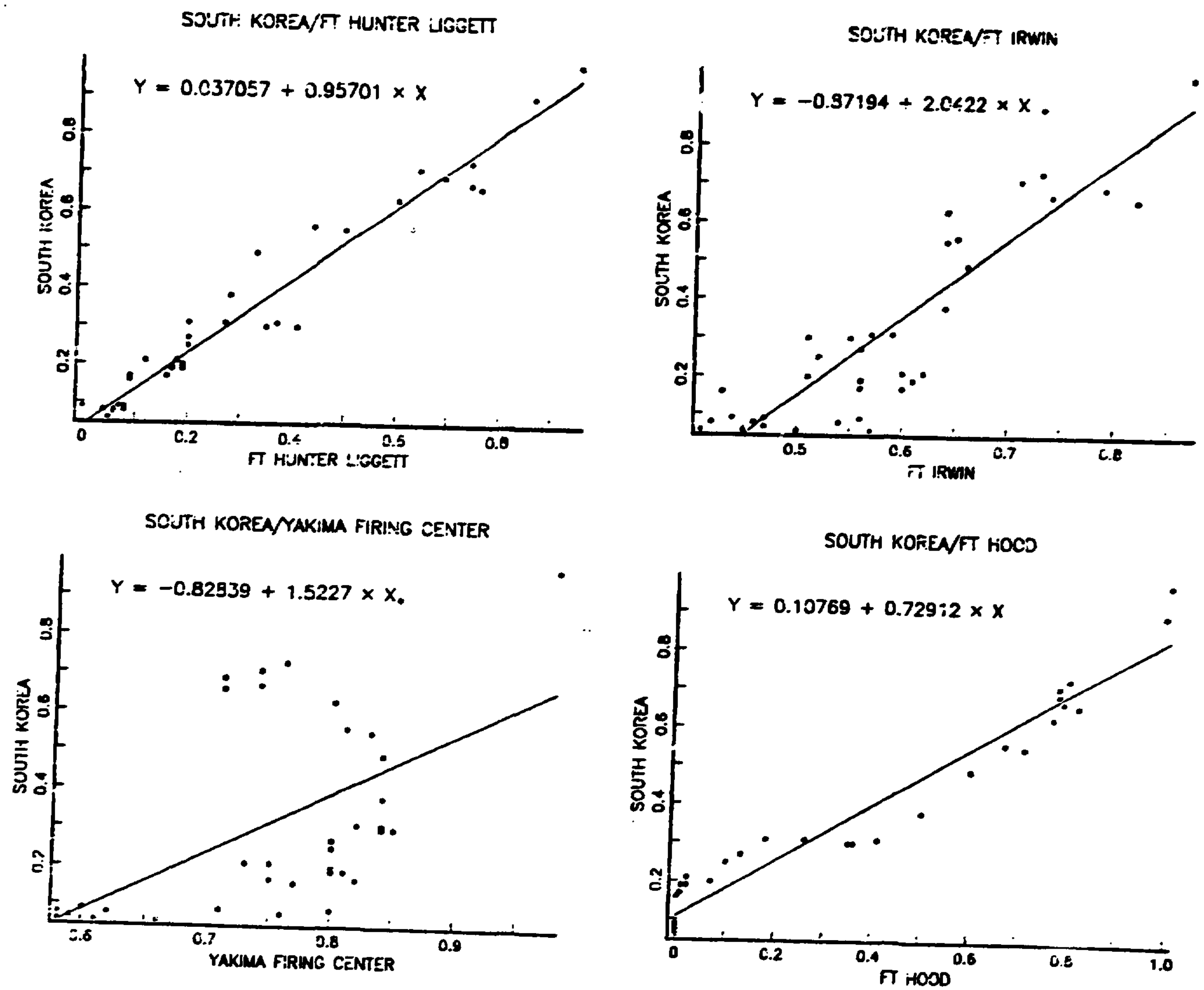


Figure E.15 Fitted Probability of Line of Sight Plots

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6.	Director U.S. Army Waterways Experiment Station ATTN: WESEN and WESGM P.O. Box 631 Vicksburg, Mississippi 39180-0631	2
7.	Bell Hall Library U.S. Army Combined Arms Center Fort Leavenworth, Kansas 66027	1
8.	Dr. Donald R. Barr Evaluation Technology Inc. 2150 Garden Road, Ste. 33 Monterey, California 93940	5
9.	Major Bard K. Mansager, Code 55Ma Department of Operations Research Naval Postgraduate School Monterey, California 93943-5000	5

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